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COOPERATIVE SALINITY CONTROL RECONNAISSANCE STUDY, UPPER COLORADO RIVER BASIN

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COOPERATIVE SALINITY CONTROL RECONNAISSANCE STUDY
UPPER COLORADO RIVER BASIN

Final Review Draft

UNITED STATES DEPARTMENT OF THE INTERIOR

Federal Water Pollution Control Administration
Southwest Region, San Francisco, California

and

Bureau of Reclamation
Region 4, Salt Lake City, Utah

February 1970

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TABLE OF CONTENTS

Chapter Page

I. INTRODUCTION 1

II. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS 5

SUMMARY 5

CONCLUSIONS 9

RECOMMENDATIONS 12

III. CAUSES OF SALINITY 14

SALT LOADING EFFECTS 14

Natural Discrete Sources 16
Natural Diffuse Sources 16
Paradox Valley 24
Sinbad Valley 24
Salt Loading from Irrigation 25
Salt Loading from Municipal and Industrial Sources 25
Municipal Waste Sources 26
Mines and Wells 26

SALT CONCENTRATING EFFECTS 27

Concentrating Effects Attributable to Activities of Man 28
Irrigation 28
Municipal and Industrial Sources 28
Out of Basin Diversions 29
Reservoir Evaporation 29
Concentrating Effects Attributable to Nature . . . 29

IV. EFFECTS OF SALINITY ON USES OF WATER 31

EFFECTS OF SALINITY ON AGRICULTURE 32

Irrigation 33
Livestock Water Supply 36

EFFECTS OF SALINITY ON MUNICIPAL USES 37

EFFECTS OF SALINITY ON INDUSTRIAL USES 39

SUMMARY OF SALINITY EFFECTS 41

V. TECHNICAL POSSIBILITIES FOR SALINITY CONTROL 44

MEASURES FOR INCREASING WATER SUPPLY 45

- Water Conservation Measures 47
  - Increased Watershed Runoff 47
  - Suppression of Evaporation 48
  - Phreatophyte Control 50
  - Optimized Water Utilization for Irrigation . . 51
  - Water Reuse 59
  - Salinity Control Effects of Water Conservation 59
- Water Augmentation Measures 61
  - Weather Modification 61
  - Water Importation 62
  - Other Considerations 65

MEASURES FOR REDUCING SALT LOADING 65

- Control of Natural Sources 66
  - Natural Discrete Sources 66
  - Natural Diffuse Sources 68
- Control of Man-Made Sources 69
  - Municipal and Industrial Sources 69
  - Irrigation Return Flows 70

VI. STATUS OF SALINITY CONTROL ACTIVITIES IN THE UPPER BASIN 75

CONTROL OF NATURAL DIFFUSE SOURCES 77

- Paradox Salinity Control Project 79
  - Bedrock Dam and Regulation Reservoir 83
  - Paradox Dam and Evaporating Reservoir 85
  - Paradox Bypass Canal 86
  - West Paradox Creek Diversion Canal 87

CONTROL OF NATURAL DISCRETE SOURCES 88

CONTROL OF FLOWING WELLS 90

- Crystal Geyser Salinity Control Project 91

CONTROL OF IRRIGATION RETURN FLOWS 96

- Treatment and Disposal of Return Flows 96
  - Evaporation 96
  - Deep-Well Injection 98
  - Desalination 99
- Minimizing Return Flow Volumes 100
  - Irrigation Management 100
  - Canal Lining 100
- Minimizing Salt Pickup 105

VII. LEGAL, INSTITUTIONAL, AND FINANCIAL CONSIDERATIONS . . . 108

LEGAL AND INSTITUTIONAL ASPECTS 109

Federal Legislation 109
Colorado River Compact 112
Mexican Treaty 113
Upper Colorado River Basin Compact 113
Arizona vs. California Suit in the Supreme Court . 113
Project Acts of the United States Congress 114
Repayment Contracts Between Water Users and the Bureau of Reclamation 115
State Water Laws and State Water Control Agencies 115
The Upper Colorado River Commission 116
Conservation, Irrigation, and Drainage Districts, and Companies and Other Water User Organizations . 116
Other Federal and State Agencies Administering Watershed Lands 117

FINANCIAL ASPECTS 118

LIST OF FIGURES

Figure		Page
1	Colorado River Basin	2
2	Sources of Salt Load in the Upper Colorado River Basin	15
3	Natural Sources of Salt in the Upper Colorado River Basin	20
4	Planar Representation of Economic Model	42
5	Location of Salinity Control Investigations in the Upper Colorado River Basin	78
6	Location of Paradox Salinity Control Project	80
7	Crystal Geyser Reservoir Site	92

LIST OF TABLES

Table Page

1 Saline Springs in the Upper Colorado River Basin 17

2 Upper Colorado River Basin Tributaries with TDS Concentrations Exceeding 750 mg/l 21

3 Upper Colorado River Basin Tributaries with Average Annual Yield of 150-200 Tons/Sq. Mi. 22

4 Upper Colorado River Basin Tributaries with Average Annual Yield of Over 200 Tons/Sq. Mi. 23

5 Technical Possibilities for Salinity Control 46

CHAPTER I. INTRODUCTION

Salinity is the most serious water quality problem in the Colorado River Basin, located in southwestern United States (Figure 1). Like many streams in the arid West, the Colorado River progressively increases in salinity (total dissolved solids and constituent salts) between its headwaters and its mouth. This results in salinity concentrations in the Lower Colorado River (below Lees Ferry, Arizona) that presently are approaching critical levels for municipal, industrial, and agricultural water use. In the face of this present situation, planned and proposed water resource development, primarily in the Upper Colorado River Basin, will cause significant increases in salinity of the Lower Colorado River. It is estimated that this development will deplete the mean annual flow of the river by more than 2,000,000 acre-feet and will increase the average annual salt load carried by the river by more than 500,000 tons, both of these changes measured at Hoover Dam. This depletion of flow will reduce the salt-diluting capacity of the river and, together with the increased salt load, will produce an estimated average increase in salinity of approximately 240 mg/l at Hoover Dam. This additional degradation of water quality will have a significant impact on water uses in the Lower Basin.

The Secretary of the Interior is authorized to undertake studies of the salinity problem by a number of legislative acts. Section 15 of Public Law 87-483, the San Juan-Chama Project and the Navajo Irrigation Project Act, directs the Secretary ". . . to study all possible means of improving the quality of such water (Colorado River) and of alleviating the ill effects of poor quality. . . ." Section 1 of the Federal Water

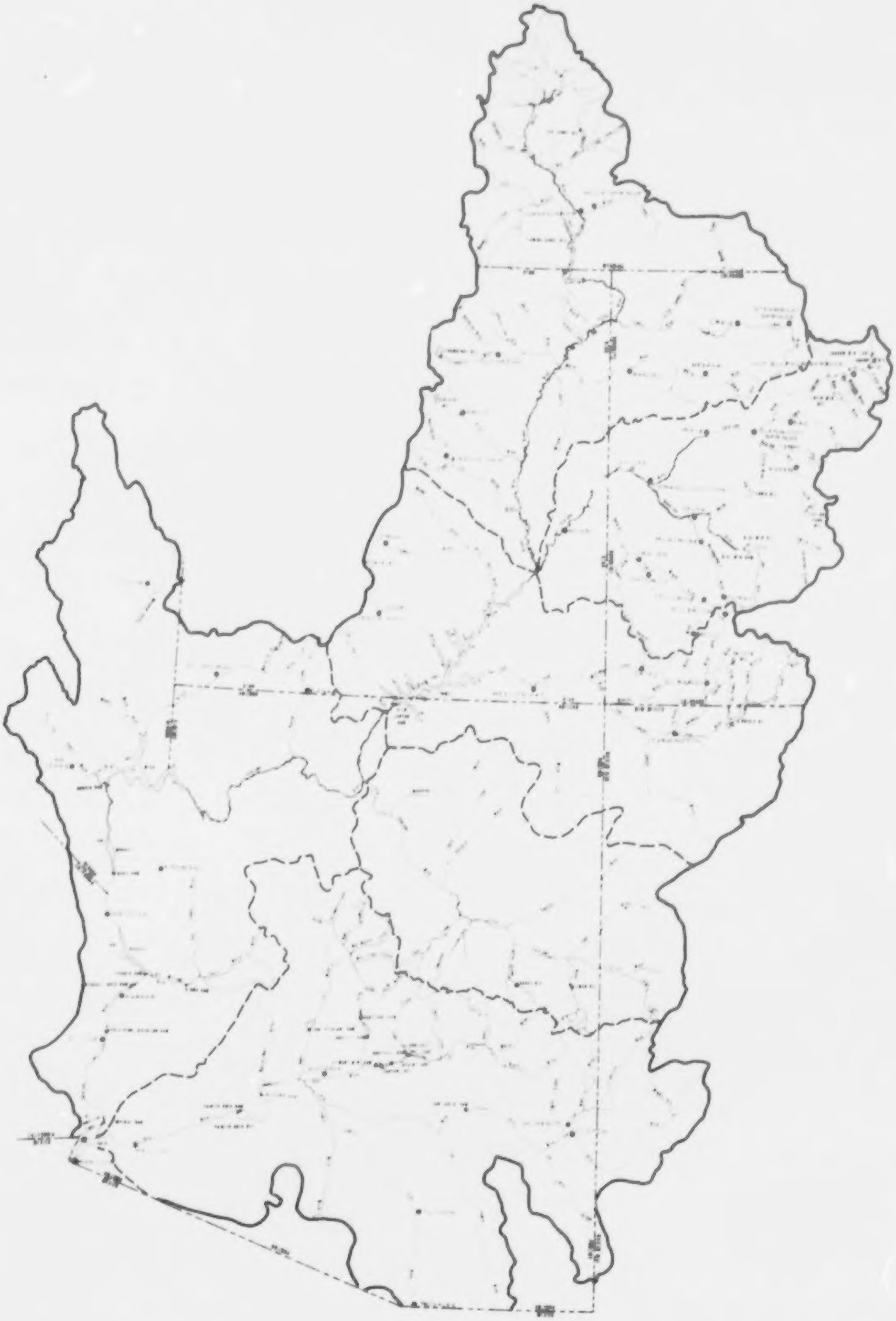


Figure 1. Colorado River Basin

Pollution Control Act, as amended, sets forth a national purpose "to enhance the quality and value of our water resources . . .", and Section 3 of this Act authorizes the Secretary of the Interior "to prepare and develop comprehensive programs for eliminating or reducing the pollution of interstate waters. . ."

Department of the Interior agencies, including the Bureau of Reclamation, the Federal Water Pollution Control Administration (FWPCA), and the Geological Survey, have, for a number of years, conducted activities in the Upper Basin related to the identification, evaluation, and control of salinity problems. In May 1967, a meeting of representatives of these agencies was held in Salt Lake City, Utah, to discuss Basin salinity problems, the activities that had been completed to date, and the role of each agency in salinity control. As a result of this meeting, a reconnaissance salinity control study of the Upper Basin was initiated jointly by the Region 4 office of the Bureau of Reclamation and the Pacific Southwest Region of FWPCA. This study was to continue for two years and to terminate in June 1969, with the completion of this reconnaissance report.

This report presents essentially the "state-of-the-art" with respect to salinity control activities in the Upper Basin. The causes of salinity are identified including a quantification of salt sources in the Upper Basin. Economic effects of salinity on water users are detailed and expected economic losses quantified. Potentially feasible salinity control measures are outlined along with associated technical limitations. Current activities related to salinity control in the Upper Basin are discussed, including feasibility studies of salinity control projects and active research and demonstration projects. The report also identifies the need for a major basin-wide salinity control program and makes recommendations concerning immediate and long-range activities in this regard.

CHAPTER II. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

SUMMARY

Salinity in the Colorado River progressively increases from the river headwaters to its mouth. This increase results from the addition of mineral salts (total dissolved solids) from various natural and man-made sources, commonly called salt loading, and the salt concentrating effects of consumptive water use.

The FWPCA estimates that a total annual salt burden of 8.2 to 8.4 million tons flows past Lees Ferry. Approximately 52 per cent of this total is estimated to be contributed by diffuse sources of natural origin, 6 per cent by discrete sources of natural origin, 41 per cent by irrigation activities, and less than one per cent by municipal and industrial sources.

Natural discrete sources are defined as springs, or seeps, which issue as a single flowing stream, or as a series of such streams within a relatively small area. These sources have been inventoried. Natural diffuse sources include surface runoff and groundwater discharges. Diffuse sources have been quantified by areal contributions.

Municipal and industrial salt sources, including oil field brines, have been inventoried. Salt contributions from irrigation activities have been estimated by inflow-outflow studies for a given geographical area.

Consumptive water use by nature and man's activity produces significant salinity increases in the Basin. Principal categories of consumptive use include natural evapotranspiration, irrigation, municipal and industrial use, export by transmountain diversions, and reservoir evaporation.

Water uses in the Colorado River Basin can be categorized as consumptive uses--municipal, industrial, and agricultural uses--and non-consumptive uses--hydroelectric power generation, water-oriented recreation, and fish and wildlife propagation. Within the range of salinity concentrations encountered in the Colorado River Basin, little detrimental effect on non-consumptive uses would be expected.

In contrast, present salinity concentrations are approaching serious levels for consumptive water uses in the Lower Basin. Salinity increases can produce detrimental effects on agricultural, municipal, and industrial uses. The effects on agricultural uses are primarily in the form of reduced crop yields and increased leaching water requirements. Salinity increases result in detriments to municipal water users in the form of increased costs for soaps, laundry additives, and water softening; accelerated fabric wear; and scaling and corrosion of water systems. Industrial water users increase expenditures for purchasing and treating cooling and boiler-feed supplies as salinity increases.

A number of the above salinity detriments can be quantified and related to salinity concentrations. The Colorado River Basin Water Quality Control Project of the FWPCA has conducted studies of the salinity problem since 1963. These studies have resulted in the development of methods for evaluating the economic impact of salinity increases. An economic model has been developed which quantifies the direct salinity detriments discussed above and also, through the use of input-output analysis techniques, evaluates the indirect impact on the economy resulting from such direct detriments. This report briefly discusses the results of the economic studies. A more detailed presentation of the economic analysis is contained in the three-volume report, "The Mineral Quality Problem in the Colorado River Basin," to be published by FWPCA in the near future.

A number of technically feasible methods of salinity control have been identified. These methods may be categorized as measures for increasing the Basin water supply available for dilution of salt loads and measures for reducing salt loading.

Available water supply may be increased by water conservation measures--watershed runoff control, suppression of evaporation, phreatophyte control, optimized water utilization for irrigation, and water reuse--and by water augmentation measures--weather modification, water importation, and water exchange. Under present legal constraints and traditional patterns of water utilization, the application of water conservation measures would produce few benefits, as any resulting increase in available water supply would most likely be utilized by a beneficial consumptive use and no additional water would be available for salinity control by dilution. However, such measures may be significantly beneficial in reducing salt loading. Also, if legal constraints were modified to make conserved water available for salinity control, significant benefits could result.

Salt loads can be reduced by controlling the various types of salt sources. Natural discrete sources can be controlled by suppressing the natural flow, by desalination of the discharge and by confinement of the discharge in evaporating reservoirs or deep geologic formations. The latter three methods are also applicable to control of salt loading from municipal and industrial sources and irrigation return flows. Salt loads from natural diffuse sources can be reduced by limiting the opportunity for surface runoff and groundwater to contact soils and formations containing high concentrations of soluble salt. Additional methods of reducing salt loading from irrigation activities include proper land selection, reduction of return flows by canal lining and improved irrigation efficiency, and installation of drainage facilities.

Although technically feasible, the practicality of applying the above methods in the Upper Basin is limited by a number of factors including legal, institutional, and financial constraints as well as economic feasibility. A number of activities have been completed or are under way to better define the practicality of various salinity control measures.

Control of diffuse natural sources is the most difficult and complex. A reconnaissance-level design has been prepared for the Paradox Salinity Control Project to control a diffuse source. The feasibility of controlling several large mineral springs was investigated but no potentially feasible control plans have been formulated. Three abandoned oil wells have been plugged with significant results in improvement of water quality. A reconnaissance-level plan has also been developed for evaporating the discharge of a well flowing as a geyser.

With regard to irrigation, several types of control measures are being evaluated. A demonstration project is under way in Grand Valley, Colorado, to evaluate the salinity control effects of canal lining. Canal lining costs have been estimated for a number of irrigation projects in the Upper Basin. Cost estimates were also prepared for disposal of irrigation return flows by evaporation or deep-well injection. These latter two methods were not considered economically feasible for the locations investigated.

CONCLUSIONS

If salinity concentrations increase as currently predicted, agricultural, municipal, and industrial water users in the Lower Basin will suffer significant economic detriments. The FWPCA estimates that these detriments may exceed an average of $17 million annually over the next 40 years. Upper Basin water users will not be seriously affected.

A major portion of the salt load and even a greater portion of the water originates above Lees Ferry; however, water entering the Colorado River below Lees Ferry generally has a higher salinity concentration than the water already in the river and contributes a substantial salt load. Evaporation from reservoirs, streams, and marshes increases the concentration even more before water reaches Imperial Dam. The full extent to which the salt load can be reduced is currently not defined. However, it is believed that it may be practical to control a number of specific sources.

The technology for controlling some types of salt sources has been developed. Additional knowledge will be required to formulate control methods for other types of sources. For most cases, the economic feasibility of salinity control has not been fully evaluated or demonstrated.

A salinity control program in the Upper Basin would primarily benefit Lower Basin water users. The benefits of such a program would be widespread and could not be readily assigned to individual water users. Salinity control of some sources is also potentially feasible in the Lower Basin. Thus, there is an urgent need for a basin-wide water quality management program with special emphasis on salinity control.

A basin-wide salinity control program should be carried out in two phases. The initial phase would be a planning effort and would seek to meet the following objectives:

1. Through expanded research, demonstration and technical investigation activities, develop the technical knowledge for control of salt sources and management of salinity.
2. Formulate plans for specific salinity control projects and salinity management measures by means of feasibility studies and systems analysis techniques.
3. Evaluate the legal and institutional constraints affecting implementation of a salinity management program and recommend changes where practical.
4. Develop alternative schemes for financing the program.
5. Evaluate a number of alternative objectives of a salinity control program such as minimizing total salinity-related costs, maintaining present salinity concentrations, etc.
6. Formulate alternative plans identified with the alternative objectives which would provide the optimum combination of salinity control projects and salinity management measures.

The cost of each alternative plan would be estimated along with associated benefits. Allocation of program costs would also be defined.

It is estimated that completion of the initial phase of the program would require at least five years. The second, or implementation phase of the program, would require at least twenty years for completion of construction of control facilities and would require perpetual operation and maintenance of some facilities. The implementation phase would include the following elements:

1. Establishment of the institutional framework of implementing a salinity management program.
2. Selection of final program objectives and an implementation plan to meet these objectives.
3. Establishment of salinity standards as a management tool.
4. Obtaining the necessary legal authorizations and financing from federal, state, and local sources.
5. Implementation of the selected salinity control plan.
6. Long-range management of salinity.

At least ten years will elapse before implementation of a salinity control program could produce significant reductions in salinity concentrations in the Lower Colorado River. Achieving results within this short a time span would require substantial expansion of current activities within the framework of the planning program described above. Projected future increases in salinity concentrations and accompanying economic detriments point out the need for early initiation of the planning program so that such economic impacts may be minimized.

The FWPCA and Bureau of Reclamation are conducting various activities in the field of salinity control which could serve as a basis for the initiation of the planning phase of a salinity control program. Both agencies have the experience and expertise which would be required to formulate, direct, and carry out the planning phase of a salinity control program.

RECOMMENDATIONS

To provide the most workable, equitable, and economically feasible degree of salinity control in the Colorado River Basin as expediently as possible, it is recommended that:

1. The planning phase of the salinity control program be initiated as soon as possible. The objectives of this phase should be the development of a number of alternative salinity management plans and the evaluation of associated costs, benefits, allocation of costs, institutional and legal constraints, financing schemes, etc.
2. The FWPCA and Bureau of Reclamation jointly carry out the planning phase of the program.
3. The active participation of federal, state, and local agencies and interest groups be encouraged during the planning phase in order to insure consideration of all factors and to aid in the development of the institutional framework for carrying out the implementation phase of the program.
4. A work plan should be developed for the planning phase by the FWPCA and the Bureau as soon as possible and funds requested

for initiation of the program at the earliest possible date and in FY 1971 if possible.

5. A target date of 1975 should be established for completion of the planning phase and presentation of alternative plans and recommendations to the seven Colorado River Basin states for their consideration and action.
6. Implementation of the second phase of the program should begin as soon thereafter as practicable in order to minimize the economic impact of future salinity increases.

CHAPTER III. CAUSES OF SALINITY

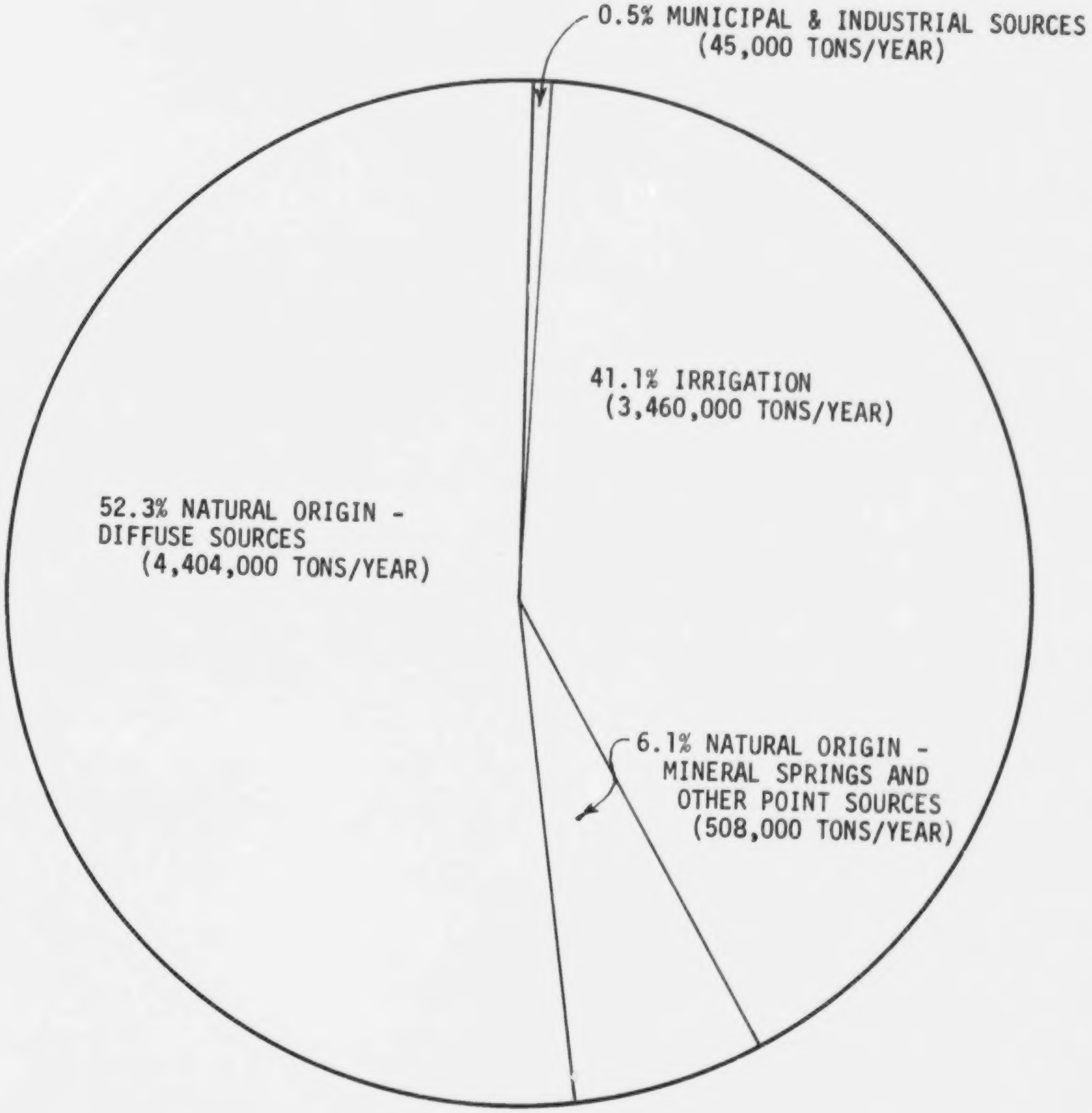
Like many streams in the arid West, the Colorado River progressively increases in salinity (total dissolved solids and constituent salts) between its headwaters and its mouth. This increase in salinity is the result of two basis processes--the addition of mineral pollutants from various natural and man-made sources, commonly called salt loading, and the salt concentrating effects of consumptive water use. Salt loading increases salinity by increasing the total salt burden carried by the river. In contrast, the increase in salinity produced by consumptive use of water results from the concentration of a constant salt burden in a lesser volume of water. The effects of these processes on Colorado River salinity is discussed in detail below.

SALT LOADING EFFECTS

Water quality records have been obtained at Lees Ferry since October 1947 with some additional periods of record prior to that time. Estimates of the average annual salt burden that would have flowed past Lees Ferry under 1960 conditions range from 8.2 to 8.4 million tons. The relative contribution of salt by natural sources and by man's activities is the subject of much disagreement. Figure 2 illustrates one estimate of proportionate sources of salt loading.

The contribution of salt from natural sources can be divided into two elements--discrete and diffuse sources. Discrete sources are identifiable discharges into the stream (such as springs and seeps) and are of much smaller magnitude than diffuse sources. Diffuse sources are defined as the base salt load brought into the river system by surface runoff and by steady inflow from underground aquifers.

Figure 2. Sources of Salt Load
in the
Upper Colorado River Basin
TOTAL LOAD - 8,417,000 TONS/YEAR
(1942-1961 Period of Record Adjusted for 1960 Water Uses)



Based on data from the following sources:

1) Geological Survey, U. S. Department of Interior, "Water Resources of the Upper Colorado River Basin, Technical Report," Professional Paper 441, 1965.
2) U. S. Department of Interior, "Quality of Water, Colorado River Basin," Progress Report No. 3, 1967.
3) Federal Water Pollution Control Administration unpublished records.

Natural Discrete Sources

Over 25 mineral springs have been located in the Upper Basin. Many of these springs are easily identifiable; others occur as seeps with some being diffuse over extensive areas. A number of these springs are highly mineralized with total dissolved solids concentrations as high as 25,000 mg/l. Springs contributing significant salt loads are listed in Table 1. As indicated by Figure 2, natural discrete sources contribute approximately six per cent of the total salt load discharged in the Upper Basin.

Many of the mineralized springs are thermal in nature. In a number of cases, these hot springs have become tourist attractions. Cities, such as Glenwood Springs and Pagosa Hot Springs in Colorado, have capitalized on these natural attractions and developed commerical enterprises. Swimming pools fed by hot springs usually discharge overflows directly into the river.

Two geysers ejecting highly mineralized water are also used as tourist attractions in Utah.

Flowing-well discharges are similar in quality characteristics to natural springs. These discrete sources are discussed under man-made sources below.

Natural Diffuse Sources

A major portion (approximately 52 per cent) of the Upper Basin salt load is contributed by natural diffuse sources. This salt is dissolved from soil and rock formations by precipitation and carried into the river by surface runoff or groundwater flow. The amount picked up is dependent upon a number of factors including the amount and solu-

Table 1. Saline Springs in the Upper Colorado River Basin[1/]
(Listed according to salt concentration)

Spring and Location	Average Concentration (mg/l)	Salt Load (T/Yr)	Flow (AF/Yr)
Salt Creek near mouth near Gateway, Colo.	24,891	3,285	97
Yampa Spring Outfall at Glenwood Springs, Colorado	18,984	121,545	4,706
Glenwood Spring area across from Yampa Spring, Glenwood Springs, Colorado	18,882	213,890	8,326
Dotsero Spring, 1.5 miles west of Dotsero, Colorado	10,898	182,500	12,307
Onion Creek Spring near Moab, Utah	9,043	1,095	89
Yellow Creek Spring near Rangely, Colo.	9,647	840	64
Ragen Spring on Muddy Creek west of Ft. Bridger, Wyoming	9,210	803	64
Steamboat Spring at Steamboat Springs, Colorado	6,112	8,432	1,014
Lithia Spring southwest of Steamboat Springs, Colorado	5,770	126	16
Seepage to Big Sandy Creek near mouth west of Farson, Wyoming	5,600	730	96
Paradise Hot Spring on West Fork Dolores River near Dunton, Colorado	5,490	621	83
Piceance Creek Spring 4.9 miles from mouth near Meeker, Colorado	3,308	72	16
Castle Creek Spring near Moab, Utah	4,390	1,059	177
Pinkerton Hot Spring at Golden Horseshoe Ranch north of Durango, Colorado	3,705	1,825	362
Trimble Hot Spring north of Durango, Colo.	3,246	106	24
Pagosa Hot Spring at Pagosa Springs, Colo.	3,223	7,300	1,665

Table 1. Contd. Saline Springs in the Upper Colorado River Basin[1]

Spring and Location	Average Concentration (mg/l)	Salt Load (T/Yr)	Flow (AF/Yr)
Ridgeway Hot Spring 1.5 miles south of Ridgeway, Colorado	2,850	2,555	659
Big Sulphur Spring on Fryingpan River near Meredith, Colorado	2,250	730	238
Cold Kendall Spring near Kendall Ranger Station, Wyoming	2,090	2,884	1,014
Arsenic Spring east of Crystal Mining Camp, Colorado	2,030	4,015	1,454
Indian Creek Spring 10 miles south of Duchesne, Utah	1,810	1,205	489
Ouray Hot Spring at Ouray, Colorado	1,668	1,643	724
Hot Sulphur Spring above bath house at Hot Sulphur Springs, Colorado	1,106	146	97
Juniper Hot Spring at Health Spa southeast of Maybell, Colorado	1,180	110	69
Warm Kendall Mineral Spring near Kendall Ranger Station, Wyoming	1,060	6,680	4,633
Heart Spring at City Pool, Steamboat Springs, Colorado	931	256	202
North Fork Trout Pond Spring on North Fork Gunnison River above Lazear, Colo.	713	3,650	3,762

1/ Based on inventory made by Colorado River Basin Water Quality Control Project, FWPCA, during 1964-1966. Other measurements indicate that the discharge and salinity concentration of several of the springs vary significantly from year to year.

bility of the natural salt, the type and permeability of the soil in which the salt occurs, the amount of percolation which takes place, the temperatures in the solution zone, and the amount of carbon dioxide present in percolating water. Variations in these factors between regions produce wide fluctuations in the salinity concentrations and salt pickup exhibited by different tributaries.

Figure 3 illustrates areal variations in diffuse salt pickup. A major portion of the salt load originates in regions where sedimentary rocks and salt-bearing sedimentary deposits dominate. In contrast, areas of igneous rock contribute low salt loads. Regions of low precipitation also exhibit low salt yields.

A selected listing of tributaries contributing significant amounts of salt are presented in Tables 2, 3, and 4. Tributaries exhibiting salinity concentrations exceeding 750 mg/1, those with an average annual salt yield of 150-200 tons per square mile, and those with an average annual salt yield of over 200 tons per square mile are listed in Tables 2, 3, and 4, respectively. The cause of high salt yield differs for each area. Studies of specific areas will be required to define the relationship of variations in salt yield to the factors discussed above.

Preliminary studies of natural sources of salt have been made by the Colorado River Basin Water Quality Control Project which show large salt yield variations in areas with similar geologic and hydrologic characteristics. These variations indicate that either (1) errors existed in the input data for the studies, (2) large unidentified sources of salt exist, or (3) some soil and rock formations may have a local high

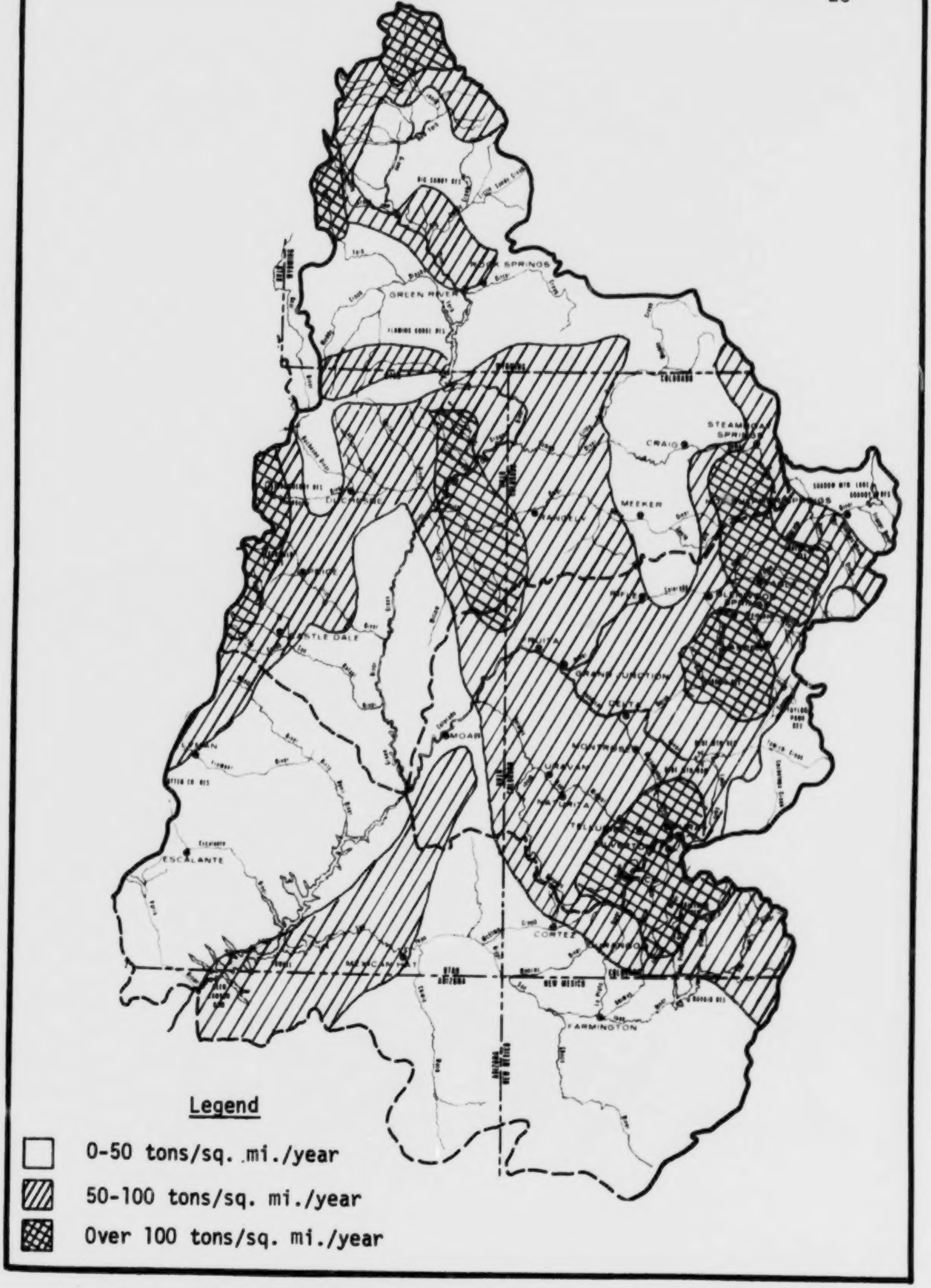

ROCK SPRINGS
GREEN RIVER
CRAIG
STEAMBOAT SPRINGS
MEEKER
RANGELY
DUCHESNE
PRICE
CASTLE DALE
RIFLE
FRUITA
GRAND JUNCTION
DELTA
MONTROSE
MOAB
URAVAN
NATURITA
TELLURIDE
ESCALANTE
MEXICAN HAT
CORTEZ
FARMINGTON
Legend
0-50 tons/sq. mi./year
50-100 tons/sq. mi./year
Over 100 tons/sq. mi./year

Figure 3. Natural Sources of Salt in the Upper Colorado River Basin

Table 2. Upper Colorado River Basin Tributaries with TDS Concentrations Exceeding 750 mg/l

Station	Drainage Area (Sq. Mi.)	Flow (A.F.)	Salt Load (T)	Concentration (mg/l)
Big Sandy Creek, Wyoming	1,610	35,350	64,280	1,340
Fortification Creek near Craig, Colorado	34	9,710	10,200	774
Ashley Creek near Jensen, Utah	386	51,580	59,900	853
Willow Creek near Ouray, Utah	967	24,700	29,220	869
Price River at Woodside, Utah	500	84,040	241,800	2,110
San Rafael River near Green River, Utah	1,690	102,100	190,300	1,370
Iron Creek near Crawford, Colorado	67	12,240	19,360	1,160
Uncompahgre River at Delta, Colorado	1,110	207,200	452,910	1,610
Roubideau Creek at mouth near Delta, Colorado	245	91,280	112,900	908
La Plata River near Farmington, New Mexico	583	22,750	28,120	908
McElmo Creek near Cortez, Colorado	233	38,760	115,100	2,180
Dirty Devil River near Hite, Utah	4,360	73,890	197,600	1,960
Paria River at Lees Ferry, Arizona	1,570	23,110	34,330	1,090

Table 3. Upper Colorado River Basin Tributaries with Average Annual Yield of 150-200 T/Sq. Mi.

Station	Drainage Area (Sq.Mi.)	Flow (A.F.)	Salt Load (T)	Concentration (Mg/l)	Salt Yield (T/sq. Mi.)
Green River at Warren Br., Wyoming	468	391,200	80,360	151	172
North Piney Creek, Wyo.	58	43,250	10,230	174	176
Hams Fork near Elk Creek, Wyoming	128	81,860	20,820	187	163
Ashley Creek near Jensen, Utah	386	51,580	59,900	853	164
Price River at Woodside, Utah	500	84,040	241,800	2,110	161
San Rafael River near Castle Dale, Utah	927	96,350	171,300	1,310	185
Gypsum Creek near Gypsum, Colorado	63	26,950	10,230	279	162
West Divide Creek, Colo.	33	21,150	5,110	178	156
Colorado River near Cameo, Colorado	8,060	2,998,000	1,578,000	387	196
East River at Almont, Colorado	295	243,400	48,580	147	165
Gunnison River near Grand Junction, Colorado	8,020	1,884,000	1,514,000	592	189
Colorado River near Cisco, Colorado	24,100	5,634,000	4,120,000	547	171
Mineral Creek, Colo.	44	76,070	8,040	78	183
Hermosa Creek, Colo.	172	106,500	31,780	219	185
Animas River, New Mex.	1,360	703,500	223,200	233	164

Table 4. Upper Colorado River Basin Tributaries with Average Annual Yield of Over 200 T/Sq. Mi.

Station	Drainage Area (Sq. Mi.)	Flow (A.F.)	Salt Load (T)	Concentration (Mg/l)	Salt Yield (T/Sq. Mi.)
Fortification Creek near Craig, Colorado	34	9,710	10,230	774	298
White River at Buford, Colorado	254	239,800	53,690	164	211
Eagle River at Gypsum, Colorado	844	436,100	179,700	303	213
Castle Creek near Aspen, Colorado	62	64,330	16,800	192	271
Crystal River near Redstone, Colorado	225	281,100	63,140	165	281
Roaring Fork at Glenwood Springs, Colorado	1,460	980,200	299,900	225	205
Iron Creek near Crawford, Colorado	67	12,240	19,360	1,160	289
Uncompahgre River at Delta, Colorado	1,110	207,200	452,910	1,610	408
Roubideau Creek at mouth, Colorado	245	91,280	112,900	908	461
Animas River at Howardsville, Colorado	56	84,760	12,780	111	229
Animas River at Durango, Colorado	692	622,300	155,200	183	224
McElmo Creek near Cortez, Colorado	233	38,760	115,100	2,180	494

salt yield that deserves particular investigation. Additional studies will be required to define the sources of such variations.

It appears that some small localized areas may contribute relatively large salt loads. Identification of such areas would allow studies to be conducted to define the feasibility of controlling such sources. Two salt sources of this nature have been identified in the Dolores River drainage area in southwestern Colorado and are discussed in the following sections. The small size of these areas relative to their salt load contribution would indicate that control may be practicable.

Paradox Valley. In the Dolores River Basin there is a series of collapsed salt anticlines. Halite and gypsum in the Paradox formation flowed plastically, apparently due to overburden loading to form a series of elongated anticlines. The saline minerals were then leached, permitting the collapse of roof material and greater exposure of the saline minerals to leaching. The Dolores River crosses two such anticlines, Gypsum Valley and Paradox Valley. For some reason, very little salt is picked up in Gypsum Valley. However, as the river crosses the narrow Paradox Valley, it picks up approximately 230,000 tons of dissolved solids annually from salt-laden groundwater discharges. During periods of high runoff, river water enters the groundwater mass to reappear at lower stages as brine. When this brine enters the Dolores River, the salt loading of the stream increases rapidly. Part of this Paradox Valley brine is pumped for use occasionally as process water in a uranium mill at Uravan, Colorado, and for preparing well drilling mud.

Sinbad Valley. Sinbad Valley is another smaller salt anticline south of the Dolores River near Gateway. During autumn and winter, there is no outflow from the valley. However, during spring and summer, Salt Creek discharges highly mineralized water from this valley into the Dolores River.

Salt Loading from Irrigation

The FWPCA reports that irrigation, the largest source of salt resulting from man's activities, contributes about 41 per cent of the salt loading in the Upper Basin. Approximately 3,460,000 tons of salt are estimated to be contributed annually by 1,430,000 acres of irrigated land, an average of 2.4 tons per acre.[1/]

Considerable disagreement exists among authorities in the field of irrigation with regard to the amount of salt leached from irrigated areas. Some authorities think that the irrigated areas contribute very little salt to the salt load. The reason for the disagreement is that the processes controlling the salinity of irrigation return flow are complex and not yet well defined. Such factors as soil types, irrigation practices, ground water salinity, etc. may have a major impact upon salt pickup from an irrigated area.

Salt Loading from Municipal and Industrial Sources

Saline pollution from industry and municipal sewage is of minor importance in terms of total salt load. This load, which is often

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[1/] Average salt loads are based on Iorn's data modified to the 1942-1961 period of record and adjusted to 1960 conditions. Average salt loads ranging from 0.7 to 2.5 tons per acre have been reported by other sources for various areas of the Upper Basin. Recent inventories indicate that the irrigated acreage may total approximately 1.62 million acres. Average salt contribution for the higher acreage would be approximately 2.1 tons per acre.

susceptible to safe disposal, represents only about one-half of one per cent of the total salt load.

Municipal Waste Sources. Based on an average annual contribution of 100 tons of salt per 1,000 population, the annual salt load contributed by municipal waste sources is estimated to be in the order of 33,500 tons. It has been observed that the salinity concentrations of municipal waste effluents range from 100 to 1,100 mg/l higher than raw water supplies.

Mines and Wells. Mining and industrial operations contribute some saline pollution to streams in the Basin. Abandoned uranium mine and mill tailings piles contain high concentrations of minerals and/or radioactive materials, which can be transported to water courses by wind and water erosion. As a result of concerted efforts by government and the uranium industry, discharges of radioactive mill wastes to streams have been greatly reduced. This action also reduces the mineral pollution problem.

The FWPCA, in cooperation with the Oil and Gas Conservation Branch of the U. S. Geological Survey, has tabulated all the discharges of saline water from oil fields in the Basin. All oil field activities were found to be in the Upper Colorado River Basin. The total oil field saline water production in 1967 was 138,663,950 barrels of water containing more than 470,000 tons of salt. Surface disposal methods, which allowed the salt to eventually reach the Colorado River, were utilized for 48,812,000 barrels of saline water containing about 15,000 tons of salt. This amount represents 35 per cent of saline water production from oil field activity but only 3 per cent of salt production. Disposal of the balance, 65 per cent of the water and 97 per cent of the salt, was achieved by either injection into wells or discharge to lined surface ponds. Saline water disposed of in this manner will have no influence on Colorado River water quality as long as it remains confined.

Most of the oil field saline water discharged to the ground surface is low in salt content compared with the water discharged underground or to lined ponds. It has beneficial uses such as irrigation and livestock watering; however, because most of these waters are used to irrigate saline soils, a high salt content in the irrigation effluent can be expected. The FWPCA will conduct further studies on the quality of these return flows as well as the feasibility of reducing the salt input to the river from this source.

A number of abandoned oil wells located at various points in the Basin (see Figure 3, Page No. 20) discharge highly mineralized water in the same manner as mineral springs. Plugging of three such wells, which together discharged more than 68,000 tons of salt annually, is discussed in Chapter VI.

Researchers studying the development of the oil shale industry in the Upper Basin have pointed out the potential mineral pollution sources represented by tailings piles. The waste solids have a high content of soluble salts which could enter stream courses if water is allowed to come in contact with them. If the industry becomes operational, stringent controls on disposal of waste solids will be required to prevent significant mineral pollution. Utilization of an in situ retort method would reduce the potential for mineral pollution from this source.

SALT-CONCENTRATING EFFECTS

Consumptive use of water attributable to both nature and the activities of man occurs throughout the Basin. Consumptive use removes essentially pure water from the river system leaving a diminished flow to carry the same salt burden with the result that salinity concentrations increase. In the Colorado River Basin, these salt concentrating effects are magnified by increases in the salt burden carried by the river as it moves downstream. Salt concentrating effects attributable to various factors are discussed below.

Concentrating Effects Attributable to Activities of Man

Four categories of consumptive water use can be attributed to the development of the Basin's water resources. As discussed in the following sections, the magnitude of this consumptive use is large and it is estimated that such use will about double within the next 50 years. Thus, the salt concentrating effects of consumptive use will be of major importance in the future.

Irrigation. Consumptive water use by irrigated agriculture accounts for the largest water loss attributable to man in the Upper Basin. It has been estimated that present irrigation use in the Upper Basin results in an annual consumptive use of 1.8 million acre-feet of water. It is anticipated that future irrigation development may increase this depletion by approximately 50 per cent by the year 2010. This increased depletion would provide for a full irrigation supply to more than 300,000 acres of new land, a supplemental supply to a number of existing irrigated areas, and increased reservoir and canal evaporation losses.

Municipal and Industrial Uses. It is estimated that the present average depletion for these uses is approximately 30,000 acre-feet annually.

Economic and demographic projections indicate that by the year 2010 municipal and industrial users, including new steam plants, will consume more than 350,000 acre-feet annually.

Out of Basin Diversions. A number of municipalities located outside the Basin obtain a portion of their municipal and industrial water supply by diversion from Basin headwaters. Additional water is exported for irrigation use. These diversions for 1960 uses averaged about 465,000 acre-feet. It is estimated that such diversions may about double by the year 2010. Thus, population and economic growth outside of the Basin will have a large impact on the water quality of the Colorado River.

The salt load carried by the diverted flow is permanently removed from the Basin. However, since the diverted flow has a low salinity concentration, the Basin is deprived of a source of high quality water for dilution of downstream salinity.

Reservoir Evaporation. The activities of man also cause depletion of water through reservoir evaporation and channel losses. Evaporative losses from the large main stem reservoirs under normal operating conditions are estimated to total 630,000 acre-feet annually. Additional losses occur from other smaller reservoirs. Proposed water resource development will not significantly increase reservoir evaporation in the near future.

Concentrating Effects Attributable to Nature

The largest water losses from the Basin can be attributed to nature and the continuing hydrological cycle. It is estimated that approximately 84 per cent of the precipitation that falls in the Basin is lost by natural evapotranspiration and deep percolation. The activities of man consume much of the remaining 16 per cent as described in the preceding section.

The natural losses include evaporation from land, water, and snow surfaces, transpiration from native vegetation, and deep percolation to closed geological formations. These losses contribute to salinity concentrations by reducing the supply of water available in the headwaters for dilution of the Basin salt burden and by depleting residual stream flow as it moves through the Basin.

CHAPTER IV. EFFECTS OF SALINITY ON USES OF WATER

A variety of water uses exists within the Colorado River Basin. These uses can be categorized as either consumptive or non-consumptive. Consumptive uses, which include irrigation, livestock watering, and municipal and industrial water supply, remove water from the river system. In contrast, non-consumptive uses such as hydroelectric power generation, navigation, water-oriented recreation, and fish and wildlife propagation utilize water *in situ*.

With regard to salinity, a second distinction between consumptive and non-consumptive water uses in the Colorado River Basin can be made. Within the range of salinity concentration predicted for the foreseeable future, no significant effects on non-consumptive water uses should result from salinity increases. However, projected salinity increases (from about 800 to 1,200 mg/l at Imperial Dam) are expected to produce significant detrimental effects on consumptive water uses.

Municipal, industrial, and agricultural water uses are the most sensitive to changes in salinity. These uses have been studied to determine what economic impact projected changes in salinity might produce. A preliminary investigation conducted by the FWPCA indicated that water users in the Upper Basin would not suffer significant adverse effects attributable to salinity increases within the foreseeable future. However, detrimental effects on Lower Basin water use would be appreciable.

A six-year detailed study of the economic structure of Lower Basin industry was completed in 1968 by the Bureau of Economic Research, University of Colorado, and the Economic Research Service, U. S. Department of Agriculture, under an FWPCA contract. This economic study is described in a report entitled, "An Interindustry Analysis of the Colorado River Basin in 1960 with Projections to 1980 and 2010 (Final Summary Report)," which is supported by six subbasin reports. This study provided the necessary data for development of an economic input-output model which evaluates changes in the economy resulting from changes in the river system salinity. The model has been utilized by the FWPCA to evaluate the probable economic detriments that will be suffered by Lower Basin water users if projected salinity increases take place. Benefits which would accrue to a proposed salinity control project can also be estimated by the model.

This report is concerned primarily with salinity control in the Upper Basin. However, since the economic impact of salinity changes is primarily limited to the Lower Basin, water users located in that area will receive the benefits produced by Upper Basin salinity control measures. Thus, a discussion of water use in the Lower Basin is germane to an understanding of the effects of salinity control in the Upper Basin.

The following sections discuss the effects of salinity on agricultural, municipal, and industrial water uses and the assumptions utilized by the FWPCA economic model to quantify these effects. Predicted water user costs incurred as a result of salinity increases and methods of determining salinity control benefits are also discussed.

EFFECTS OF SALINITY ON AGRICULTURE

Agricultural uses account for approximately 85 to 90 per cent of the consumptive water use in the Lower Basin. Thus, salinity effects on agriculture are of major importance to the Basin economy. Almost all of the agricultural supply is utilized for irrigation with a small amount providing livestock water. Farmstead drinking water is normally obtained from local sources. Thus, Colorado River water quality has little impact on farmstead uses.

Irrigation

In general, an increase in the salinity of an irrigation supply beyond a given threshold results in a decrease in the economic return to the irrigator. In the Lower Basin, salinity is approaching critical levels for some types of irrigated crops. Thus, economic penalties associated with small increases in salinity may be large.

Crop yields are affected by the salinity of soil moisture in the root zone. Soil salinity must be maintained below a given level for each type of crop or the crop will not survive. Between some low level of salinity and the maximum tolerance of the crop, increases in soil salinity result in progressive decreases in crop yield.

In addition to the effects produced by total dissolved solids concentrations, the absolute and/or relative concentrations of specific ions in irrigation supplies may exert detrimental effects on plant yield and survival. Thus, high concentrations of chlorides may seriously impare plant growth even though salinity concentrations are not considered adverse. Serious crop damage can result if the concentration of sodium ions becomes high relative to other ion concentrations.

Consumptive use of essentially pure water by transpiration from crops and evaporation from the land surface results in the concentration within the soil of salts dissolved in irrigation water. Thus, soil moisture salinity progressively increases unless excess water is applied to leach the accumulated salts from the root zone. In humid climates, leaching is accomplished by the excess of percolating rain and snow water. In arid climates there is no such natural excess, and the leaching must be accomplished by application of irrigation water in excess of the normal growth requirements.

Increases in the salinity of applied irrigation water result in related increases in the salinity of soil moisture if application rates remain constant; or, if soil salinity is to be maintained at a constant level, additional leaching water will be required. Thus, when a water user is confronted with an increase in the salinity of the irrigation supply, one of several alternative courses of action must be selected, each of which represents an economic loss to the water user.

If the irrigation supply is limited, the water user may be restricted to present water deliveries. In this case, three alternative courses of action are possible. Present irrigated acreage and crops may be maintained (no change alternative). This action results in an economic penalty to the water user since crop yields will be reduced. A second alternative is to alter the types of crops grown by switching from salt-sensitive crops to salt-tolerant crops. This also results in an economic penalty as salt-tolerant crops generally produce a lower economic return than salt-sensitive crops. The third available alternative is to reduce irrigated acreage and increase the application of water per acre in order to maintain present crop yields. This action also reduces the economic return to the irrigator.

When an adequate irrigation supply is available, a fourth alternative course of action may be followed: The irrigator may apply additional leaching water to his present acreage to maintain present soil salinity and crop yields. The amount of irrigation water needed for leaching is related to the salinity of the applied irrigation water. Any increase in the salinity of an irrigation water supply results in an economic penalty since more water is required for equivalent service. This is a large, although sometimes unrecognized, economic loss caused by degraded irrigation water.

Several other associated economic detriments may be incurred by the selection of this alternative. In some cases the required rate of application of the leaching water may exceed the transmitting capacity of the soil. This problem may be corrected by the installation of artificial drainage facilities such as drainage ditches or lines of buried tile drains. However, in heavier type soils, installation of drains may not be economically feasible and the irrigator is then constrained to the same alternatives as though his irrigation supply were limited. In the arid and semi-arid areas of the Southwest with their porous soils, this type of drainage problem is rarely encountered.

Water percolating through the plant root zone will remove applied fertilizers as well as mineral salts. The nitrate fertilizers are especially susceptible to loss this way because of their high solubility. As additional water is applied for leaching to maintain salt balance, an additional amount of fertilizer must be applied to the land to offset the loss of fertilizer dissolved by the additional leaching water.

Finally, when additional water has to be applied for leaching purposes, more frequent application of water is normally required, and this causes increased labor costs.

In most cases, the least cost alternative to irrigation water users will be to maintain the same rate of water application and the same irrigated acreage and thereby suffer an economic loss as a result of decreased crop yields as the salinity of the irrigation supply increases. The FWPCA economic model utilized this alternative to evaluate the economic impact of salinity increases on irrigation water users. Economic effects were computed for the Colorado River Indian Reservation, irrigated areas in Yuma County, Arizona, and the Palo Verde and Imperial Valley Irrigation Districts in California. These are the principal irrigation districts in the Colorado River Basin and are located in the Lower Basin where the largest salinity increases are expected to occur.

Livestock Water Supply

Water safe for human use is also safe for livestock. In fact, ordinary types of livestock have much higher salt tolerance than human beings. Animals can adjust within limits to consumption of saline water that they first refuse to drink. However, a sudden change from good quality to poor quality water can cause acute salt poisoning and rapid death.

The salt tolerance of an animal depends upon several factors including species, age, physical condition, season of the year, diet, and quality and quantity of the salts present. Water with a total dissolved solids concentration under 2,500 mg/l has been classified as acceptable-to-good for use as livestock water. Except for short reaches of a few tributary streams, all surface waters of the Colorado River Basin normally fall within this class. Thus, no economic detriments were determined for this use.

EFFECTS OF SALINITY ON MUNICIPAL USES

The U. S. Public Health Service Drinking Water Standards recommend a limit of 500 mg/l on total dissolved solids in public drinking water supplies. This limit has been widely used in the United States to define acceptable drinking water supplies. However, a number of municipalities in the Southwest utilize supplies exceeding this concentration of salinity.

This limit has been exceeded in the Lower Colorado throughout the period of historic record, and salinity presently ranges from 700 to nearly 1,000 mg/l in the reaches below Hoover Dam. Hardness associated with this degree of mineralization varies from about 300 to 450 mg/l. Although such water is presently used for municipal supplies, any increase in hardness intensifies detriments incurred by such use. Some of the principal ill-effects and economic impacts of high salinity and hardness are described below.

In extreme cases mineralization may render a public water supply unfit or highly undesirable for human consumption. Detriments may be assessed by estimating (1) the cost of obtaining water rights and developing a new water supply, (2) the loss associated with abandoning the existing supply, and (3) the difference in operation and maintenance costs between the old and new water supply facilities.

Where community action is not taken, mineralized water supplies may lead consumers to purchase bottled water of better quality and taste.

Perhaps the cost of bottled water could, therefore, be considered as an economic detriment. However, this premise is debatable unless an existing water supply is unfit for use. The purchase of bottled water could be considered an indulgence or luxury. While bottled water may be necessary for some domestic uses such as infant formula preparation and for use in steam irons, it is unrealistic to expect a public water supply to furnish tap water suitable for such special needs.

A highly mineralized water supply can be made more suitable for domestic use by water softening. Such treatment may be accomplished by a municipal plant or by individual home water softeners. In either case treatment costs increase as hardness increases. Resulting increments of treatment costs can be related to anticipated increases in the hardness of the water supply.

To achieve laundering results with hard water comparable to results obtained in soft water, additional laundry soap or detergents must be used; or alternatively, softening additives must be used in the wash water. Thus, communities which have hard water supplies but do not elect to provide softening nevertheless incur penalty costs in the form of higher expenditures for soap, synthetic detergents, and softening additives. Such costs are normally greater than those which would be incurred in a central softening treatment plant. In areas where portions of the population receive softened water and others do not, the detriments due to hardness are the sum of two items: operation and maintenance of softening equipment for that portion which benefits by such treatment plus the additional cost of soap and detergents incurred by the remainder of the community.

The corrosiveness of water is governed by many factors such as temperature, presence of dissolved gasses, acids and mineral salts, and electrochemical properties of the materials utilized. No simple relationship exists between the levels of mineral salts present and corrosiveness. Therefore, translation of such a relationship into tangible economic detriments is difficult. Scaling, as evidenced in home hot water systems such as water heaters, is also difficult to assess in terms of monetary values.

It has been stated that laundering with hard water hastens the wear of clothing and other textile products. One reference cites a 25-per cent faster rate of wear with hard water than with soft. However, the relationship of fractional changes in hardness to fabric wear is difficult to quantify.

Most of the communities obtaining their municipal supplies from the Lower Colorado River do not soften their water. To simplify the determination of the economic impact of salinity on municipal uses, the increased cost of soap and other laundry products utilized in these communities was assumed to represent total economic detriment costs. These costs were calculated for the communities of Las Vegas, Nevada; Parker and Yuma, Arizona; and Needles, Blythe, and Imperial Valley towns in California. A modified form of Howson's equation relating water hardness to soap costs was used for the model calculations.

EFFECTS OF SALINITY ON INDUSTRIAL USES

Four categories of industrial water use may be defined: (1) cooling, (2) boiler feed, (3) processing, and (4) sanitation and general purpose. Cooling water supply is by far the largest of these categories, varying from about 57 per cent to 80 per cent of industrial use in various areas of the Colorado River Basin. Boiler feed water demand is relatively small, from four to nine per cent of the total. Process water requirement varies widely according to location and type of industry; in southern California where industrial development is greatest, it accounts for about 25 per cent of the total industrial demand. General purpose water requirement is but a minor fraction of perhaps three to six per cent. The quality requirements in this last category are practically the same as for municipal water supply.

The water quality requirements, and hence the adverse effects of degraded water, are almost infinitely varied for process waters. Thus, a reasonable estimate of the economic effects of salinity changes on process water use for an entire basin cannot be made. However, the quality requirements for cooling and boiler feed uses are relatively consistent. Thus, the FWPCA economic model determined the effects of salinity on industrial use by evaluating economic effects of salinity on cooling and boiler feed uses.

The detriments of degraded mineral quality in cooling water use arise from two causes: (1) the need to use a greater volume of makeup water in order to maintain salinity within tolerable limits in the cooling water system and (2) the necessity to treat this extra volume of water in order to inhibit corrosion and scale formation. The relationship between hardness of the supply and the cost to industrial users was quantified by the economic model.

The effects of hard and saline water in boiler feed have also been quantified for low-pressure boiler systems, the type generally employed in manufacturing industry. The effects of a mineralized water supply, namely, corrosion, scaling, foaming, and caustic embrittlement of metals, must be controlled by limiting salinity in the boiler water system. The harder the original supply, the greater must be the volume of blowdown and makeup water. The cost of this additional makeup water and the expense of treating it (around 40 cents per thousand gallons) represent the economic detriment of a mineralized supply in this type of industrial use. Industrial user costs for makeup water and treatment were calculated by the economic model. These users are principally located in the Las Vegas area and California costal areas served by the Metropolitan Water District.

SUMMARY OF SALINITY EFFECTS

The impact of increased salinity upon economic growth in the entire Colorado River Basin was analyzed by the FWPCA's regional input-output model. This model was run for target years 1960, 1980, and 2010. Economic impacts upon agricultural, municipal, and industrial uses were determined by the model as discussed previously in this chapter. Figure 4 presents the model results for the three target years. Note the rapid rise in direct costs to water users as salinity increases. Increases in economic activity between target years are related to expected population increases. The dashed line intersecting the target-year economy lines at Points X, Y, and Z represents a combination of the expected economic and salinity trends as projected by the model.

The use of the model to compute salinity control benefits can be illustrated by the following example: The model predicts that average salinity concentration at Hoover Dam will be 876 mg/l in the year

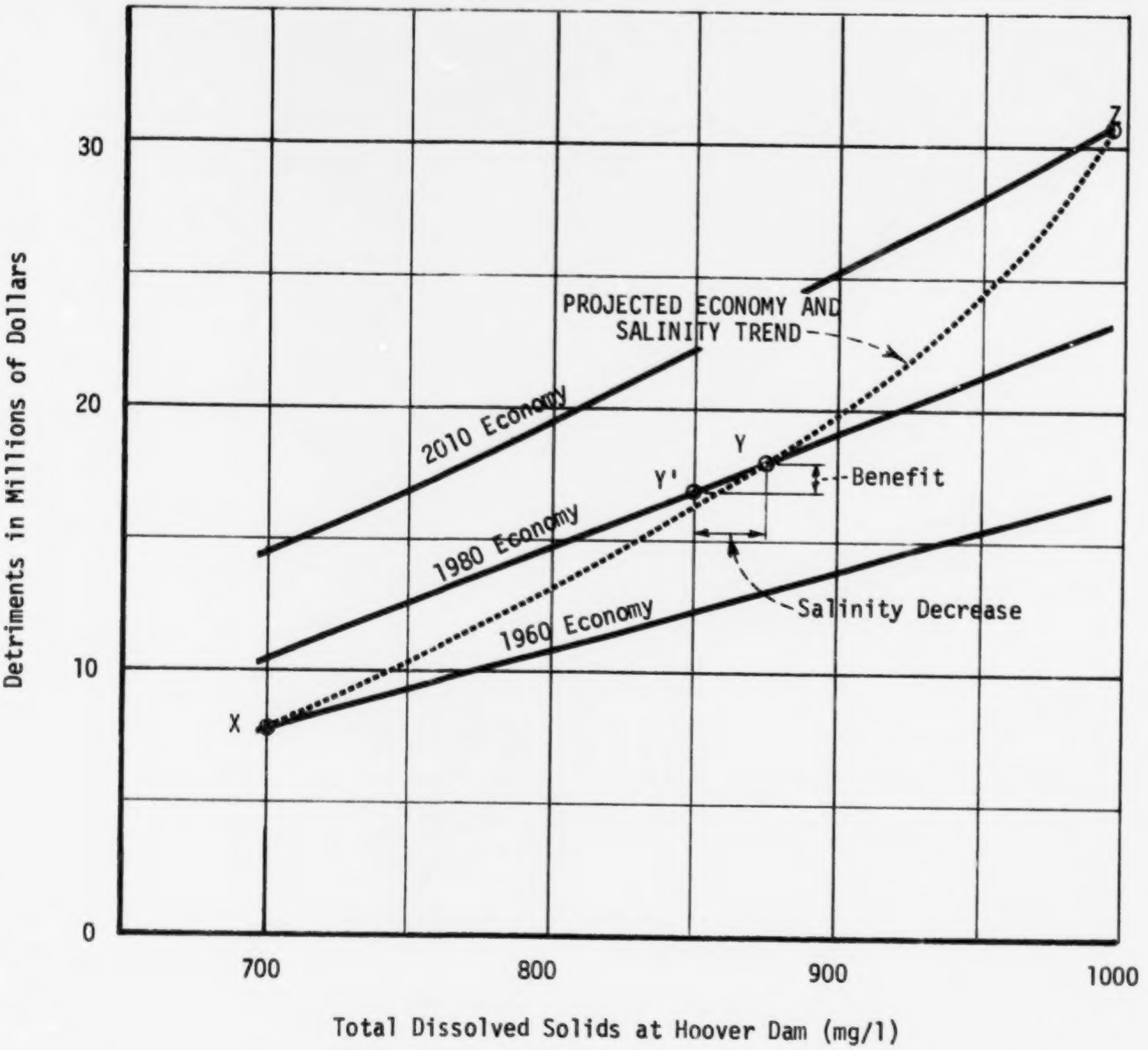

Figure 4. Planar Representation of Economic Model

1980 and direct user costs will total $17.9 million annually (Point Y on Figure 4). If a salinity control project were constructed at that time which would reduce the average salinity concentration at Hoover Dam to 850 mg/l, the model would predict a reduction in direct user costs to $16.7 million (Point Y^1). Thus, the reduction in user costs of $1.2 million represents a benefit accruing to the salinity control project for the year 1980. Similar benefits can be computed for successive years and average annual benefits can be derived.

Due to the expected changes in total salt burden and water delivered to Hoover Dam, the interrelationships between salt load reductions, salinity changes, and direct user costs are not constant but are dependent upon time. Thus, the relative impact of a salinity control project is dependent upon its time of completion. To achieve a 10-mg/l decrease in salinity at Hoover Dam in 1980, a reduction in salt load of approximately 120,000 tons per year would be required. To achieve the same salinity reduction in 2010 would require a lower salt load reduction of 110,000 tons per year. Controlling the same salt load would thus produce slightly higher benefits each successive year. In the example presented, a salt load reduction of approximately 310,000 tons per year would be required to produce average benefits of $1.5 million per year from 1980 to 2010.

CHAPTER V. TECHNICAL POSSIBILITIES FOR SALINITY CONTROL

Salinity increases result from many diverse factors; therefore, methods of controlling salinity are also diverse. However, since those economic detriments suffered by water users are the result of high salt concentrations, the objective of any salinity control activity is to reduce such concentrations.

A number of salinity control methods have been identified which are technically feasible and may be applicable to salinity problems in the Colorado River Basin. These methods are discussed in detail in this chapter. Not all of the methods are economically feasible at this time. Current efforts in evaluating the economic feasibility of several control measures are discussed in Chapter VI.

Two basic processes, salt loading and consumptive water use, were identified in Chapter III as the causes of salinity increases. Two types of salinity control measures, water-phase and salt-phase methods, may be employed to control these processes.

Water-phase measures are those employed to reduce salinity concentrations by increasing the volume of water available for dilution of a given salt burden. This can be accomplished by conserving the water supply presently available in the basin or by increasing the basin supply through importation or weather modification.

Salt-phase measures function to reduce salinity by reducing the salt load discharged to the river system. Since the sources of salt are diverse, a large number of potential control methods exist.

Specific control measures considered potentially useful in the Colorado River Basin are outlined in Table 5. The possibilities for application of these methods in the Upper Basin are discussed in detail in the following sections.

MEASURES FOR INCREASING WATER SUPPLY

A never-ending hydrologic cycle has operated in the Colorado River Basin since the Basin was formed. Although highly variable from year to year, the Basin receives a relatively fixed total water supply from atmospheric precipitation. Much of this supply is depleted by evapotranspiration with only a small fraction leaving the Basin as the discharge of the Colorado River. Under virgin conditions, evapotranspiration occurred from native vegetation, from natural water courses, and from land and snow surfaces.

Development of the Basin's water resources has increased water losses in several ways. Construction of large reservoirs and canal systems has increased evaporation from water courses. The development of irrigated areas has increased the vegetation present in the Basin and accompanying transpiration losses. Irrigation has also raised the groundwater table in many areas which has been accompanied by increased growth of native vegetation and increased evaporation from the land surface. Together, these losses have substantially reduced the water supply remaining to carry mineral salts out of the Basin.

Much time and effort has been directed toward understanding the natural processes which make up the hydrologic cycle. As a result, a number of techniques have been developed for minimizing evapotranspira-

Table 5. Technical Possibilities for Salinity Control

- I. Measures for Increasing Water Supply
    - A. Water Conservation Measures
        - 1. Increased Watershed Runoff
        - 2. Suppression of Evaporation
        - 3. Phreatophyte Control
        - 4. Optimized Water Utilization for Irrigation
            - a. Reduced Consumptive Use
                - (1) By reduced irrigated area
                - (2) By crop selection
            - b. Improved Irrigation Efficiency
                - (1) By proper land selection
                - (2) By irrigation management
        - 5. Water Reuse
    - B. Water Augmentation Measures
        - 1. Weather Modification
        - 2. Water Importation
            - a. Fresh Water Sources
            - b. Demineralized Sea Water
- II. Measures for Reducing Salt Loading
    - A. Control of Natural Sources
        - 1. Natural Discrete Sources
            - a. Evaporation of Discharge
            - b. Injection into Deep Geological Formations
            - c. Desalination
            - d. Suppression of Discharge
            - e. Reduction of Recharge
        - 2. Natural Diffuse Sources
            - a. Surface Diversions
            - b. Reduced Groundwater Recharge
            - c. Reduced Sediment Production
    - B. Control of Man-Made Sources
        - 1. Municipal and Industrial Sources
            - a. Evaporation
            - b. Injection into Deep Geological Formations
            - c. Desalination
        - 2. Irrigation Return Flows
            - a. Proper Land Selection
            - b. Canal Lining
            - c. Improved Irrigation Efficiency
            - d. Proper Drainage
            - e. Treatment or Disposal of Return Flows

tion. Along with water reuse, these techniques can be classified as water conservation measures.

Study of the hydrologic cycle has also yielded methodology for modifying precipitation. Weather modification and water importation are two activities which can be classified as water augmentation measures. The technical merits of water conservation and augmentation measures are discussed in the following sections.

Water Conservation Measures

Water may be conserved at a number of points as it passes through the various phases of the hydrological cycle. In the Upper Basin, conservation measures may be applied in the headwaters watershed, in the river and reservoir system, and at the point of consumptive use.

Increased Watershed Runoff. Man has attempted to modify the natural vegetative cover of watersheds in a manner which would reduce the rate of runoff following precipitation. Such modification produced several effects including reduced flood flows, reduced sediment production, and higher base flows during low-flow periods. This latter effect contributed to the belief that holding precipitation on the watershed increased the watershed yield.

From a salinity control viewpoint, the present practices of watershed management may be detrimental. We know that holding precipitation on the watershed increases evapotranspiration and decreases watershed yield. Also, salt pickup from the watershed increases in proportion to the length of time precipitation is stored in the soil or groundwater aquifers. Thus, rapid runoff from a watershed produces lower salinity concentrations in most cases.

The U. S. Forest Service and various state agencies are experimenting with forest management practices as a means of increasing watershed yields and rates of runoff. Some of the practices under study include forest cutting, logging and slash disposal, conversion of bushland to forest, burning of underbrush, and grazing.

A large portion of the Upper Basin runoff originates in mountain forest areas. Thus, increasing the yield and reducing the salt contribution of forest areas could have a major impact on salinity problems. However, increasing rates of runoff could produce adverse effects such as increased sediment concentrations in streams, reduced low-flow volumes with accompanying warmer water temperatures, and degraded fish and wildlife habitat. Investigations conducted jointly by appropriate state and federal agencies are needed to determine if watershed management techniques can be modified to improve the quantity and quality of watershed yields without causing the adverse effects as outlined above. Investigations of techniques for increasing the rate of runoff from non-forested areas, such as the covering of catchment areas, are also needed. No estimates are currently available of the increases in watershed yields or decreases in salinity concentrations that could be achieved by application of such methods.

Suppression of Evaporation. Water losses by direct evaporation from the surfaces of reservoirs, lakes, streams, and canals are large. Annual losses from Upper Basin mainstem reservoir evaporation alone are estimated to be 630,000 acre-feet under normal operating conditions. Such losses increase salinity concentrations by reducing the water available for dilution of a given salt burden.

The volume of water lost by evaporation is dependent upon the area of exposed water surface, intensity of solar radiation, air and water temperature, wind velocity, and relative humidity. Since the latter four factors are essentially uncontrollable, research in controlling evaporation has been directed toward developing economical methods of reducing the surface area exposed to the elements.

One obvious control method for reservoirs is to maintain the water surface at the minimum area practicable. However, operating requirements place serious constraints upon maintenance of a minimum area. Also, reservoirs in the Colorado River Basin are located primarily in relatively narrow, steep-sided canyons. Consequently, significant reductions in storage produce relatively small reductions in surface area.

A significant amount of research effort has been devoted to development of chemical covers for reservoirs such as monomolecular films. Such films have proven effective in suppressing evaporation but their cost and tendency to be broken up rapidly by wind action or biological activity reduce their practicality.

No practical methods for reducing evaporation from flowing streams have been developed.

Evaporation losses can be reduced by covering canals and by using pipe distribution systems. The use of pipe systems also reduces seepage losses and, in some cases, the pickup of salt by return flows is decreased. The feasibility of installing pipe distribution systems is dependent upon a number of factors, and construction cannot be justified on the basis of evaporation reduction alone.

The magnitude of evaporation losses is such that research should be continued to develop economical methods of suppressing evaporation. The salinity control effects of enclosed distribution systems should receive further study to determine if additional benefits would justify the installation of this effective evaporation control device.

Phreatophyte Control. Phreatophytes are non-beneficial vegetation with a high rate of consumptive water use. Phreatophytes are found in areas where the groundwater table is near the surface allowing the plants to derive their water supply from groundwater. In the Upper Basin, phreatophytes grow primarily in narrow strips along the banks of streams and reservoir shorelines. Phreatophyte surveys of several river basins in western Colorado, conducted by the U. S. Department of Agriculture, indicate that phreatophyte growths cover a total of approximately 100,000 acres in the surveyed basins. No surveys have been made in other areas of the Upper Basin. Assuming the relative area of phreatophyte growth to be comparable to the surveyed basins, phreatophyte areas are estimated to total approximately 250,000 acres in the Upper Basin. Based on an estimated consumptive use of 2.7 acre-feet per acre, water losses attributed to phreatophytes total 675,000 acre-feet annually. Thus, such losses approximate reservoir evaporation losses in magnitude with comparable effects on salinity.

Phreatophytes may be controlled by lowering the water table below the depth of root penetration and by removing or destroying the plants by mechanical or chemical means. In most cases where the water table is not lowered, controls must be continued to prevent regrowth. Revegetation of the cleared areas with beneficial crops or with plants having a lower consumptive water use may be a satisfactory method of long-range control.

Some phreatophytes provide erosion control and shelters for livestock. Other phreatophytes provide wildlife habitat. The feasibility of removing such growths would be dependent upon the practicality of providing suitable substitute vegetation with lesser consumptive water use.

Costs of phreatophyte control have ranged from a few dollars to over one hundred dollars per acre in several study areas. Revegetation of cleared areas would increase this cost. The economic feasibility of several control projects in the Lower Basin has been demonstrated based upon water salvage benefits. Investigations of control costs and resulting salinity control and water salvage benefits are needed to define the economic feasibility of phreatophyte control in the Upper Basin.

Optimized Water Utilization for Irrigation. A number of areas in the Upper Basin have been irrigated since the latter part of the nineteenth century. Irrigation practices in many areas have not changed significantly from the traditional methods developed by the early irrigators. Prior to the construction of storage reservoirs and modern canal systems, irrigation supplies were obtained by direct diversion from flowing streams. Streamflow was high during the spring snowmelt but dwindled to very low levels during late summer. A heavy application of irrigation water was made in the spring with the hope that storage in the soil would offset a deficiency of supply in the latter part of the growing season. Such application methods resulted in poor irrigation efficiencies and excessive water diversions.

With the construction of storage reservoirs to even out the seasonal supply, irrigators were slow to adopt more efficient irrigation practices. In many cases water rights were based on the excessive diversions formerly made. Irrigators were reluctant to reduce water diversions as part of their water rights could be lost. Thus, on the average, irrigation efficiencies are less than optimal in the Upper Basin and significant water conservation could be achieved by optimization of water utilization.

Water use for irrigation can be minimized by reducing consumptive use through proper selection of land and crops or by improving irrigation efficiency through proper irrigation management. These conservation measures are discussed below.

> Reduced Consumptive Use. The total water consumptively used by a given irrigation project is dependent upon the consumptive use per acre of growing crops, the total irrigated acreage, and the volume of non-beneficial losses such as evapotranspiration by phreatophytes supported by wasted water. Reduction of any one of these factors will conserve water.
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> Different crops have different water requirements. Consumptive use of water could be decreased by growing crops that use less water per unit of food or fiber produced. Thus, water conservation could be effected by promoting the raising of the most efficient water-using crops of equal economic value. The development of new crop varieties that are highly efficient in water utilization would achieve additional conservation.

A number of irrigated farms scattered throughout the basin provide only a marginal economic return to their owners. These farms may be limited to inefficient operation by poor soils, poor drainage, marginal or inadequate water supply, or other factors. Eliminating the irrigation of farms that are not economically efficient would reduce irrigated acreage and consumptive use. Factors that limit the practicality of such action include the difficulty in evaluating which farms should stop irrigating, the problems in transferring water rights, and possible relocation of farm owners or tenants.

Inefficient irrigation practices waste water which may support substantial consumptive use by non-beneficial vegetation located on non-irrigated land. Improvement of irrigation practices as discussed below would help reduce such non-beneficial use.

Improved Irrigation Efficiency. In normal practice, the volume of water supplied to an irrigated area is much larger than the volume of water consumptively used by growing crops. The ratio of the volume consumed to the volume supplied is known as the irrigation efficiency and may be determined for a number of different points in an irrigation system such as the supply reservoir or the farm headgate. Improving irrigation efficiency reduces the gross supply that must be provided for a given irrigated area and may reduce consumptive use in some cases as discussed above.

Unnecessary water losses occur at a number of points in the irrigation cycle. Efficient irrigation requires the application of only enough water to meet the consumptive use requirement of crops plus some excess flow to leach accumulated salts from the root zone (termed the leaching requirement). Thus, efficiency can be improved by reducing all other water losses. Control of these losses by proper land selection and irrigation management techniques is discussed below.

Land characteristics such as soil type, soil permeability, land slope, surface drainage patterns, and depth to the water table or impermeable barrier are limiting factors in obtaining high irrigation efficiencies. Thus, proper selection of new land for irrigation can eliminate those areas that would require excessive water supplies for crop production. Classification of existing irrigated areas with respect to land characteristics would allow identification of those areas which possibly should be removed from irrigation because of serious limitations on obtainable irrigation efficiencies.

In many systems, large volumes of water are lost by seepage from canals and distribution systems between the point of diversion from the stream or the storage reservoir and the farm. Reduction of seepage losses by lining canals and constructing pipe distribution systems can substantially increase overall irrigation efficiency.

Perhaps the most significant factor affecting farm irrigation efficiencies is the management of both the timing and method of application of irrigation water. By timing the application to meet crop requirements and by selection of the method of application to match crop and land characteristics, high efficiencies can be obtained. It is estimated that improved irrigation methods and practices could reduce the farm irrigation requirement by as much as 30 per cent.

Early irrigation projects operated without storage reservoirs and were limited to delivery of water when adequate streamflow was available. This resulted in the inefficient practice of applying irrigation water when it was available regardless of whether or not the soil could store it. Construction of storage reservoirs has made it possible for water to be delivered to the farm on demand in a number of irrigation projects. However, farmers have been slow to revise their irrigation practices in many cases. Thus, a program to educate and assist irrigators in the proper timing of irrigation could significantly increase from efficiencies.

A program of this nature is provided by the Salt River Water Users in Arizona. An agent calls on the farmer weekly and, with the farmer, samples field soil moisture and determines irrigation requirements for the next week. Another such program in Idaho helps the irrigator by computing the consumptive use for the year to date and forecasting the consumptive use for the coming week. By use of records of irrigations, soil capacity, and crop conditions, an estimate of the date of the next needed irrigation is supplied the irrigator. Probably a combination of these two systems would be most advantageous for an individual irrigator.

Consolidation of irrigation companies, canal companies, irrigation districts, drainage districts, and private ditch companies or users into one unit for an irrigated area would provide an organization for establishing the above program and would also allow more efficient distribution of the available irrigation water. A single entity controlling all of the irrigation and drainage systems in an area could promote more efficient irrigation by establishing rules for determining irrigation needs, economic incentives for installing more efficient irrigating methods or systems and practices, and establishing penalties for misuse of irrigation water.

Construction of storage and equalizing reservoirs for those projects obtaining irrigation supplies by direct diversion from uncontrolled streams would allow major improvement in farm efficiencies in these areas by changing to a demand system of irrigation. An example of potential improvement is provided by the Vernal Unit of the Central Utah Project.

Prior to 1963 the rotation system of irrigation existed in Ashley Valley. The completion by the Bureau of Reclamation of Steinaker Reservoir in that year was the incentive for integration of five canal companies into a central office and the inauguration of the demand system of irrigation. Now a specified amount of water can be called for by the farmers when they need it. Soil Conservation officials in Uintah County estimate that the overall irrigation efficiency has improved by 20 per cent. A stockwater pipeline was also installed to prevent seepage and water logging of the soils during the non-irrigating season.

Proper selection of methods of applying irrigation water can significantly improve farm efficiencies. Use of such methods as border strips, furrows, corrugates, and sprinkler systems can produce field application efficiencies of over 50 per cent.

Sprinkler systems can be operated to give the highest obtainable irrigation efficiencies ranging from 60 to 75 per cent. However, sprinkler systems are not always economical for the irrigator. Also, some crops produce better yields when irrigated by systems other than sprinklers, and crops such as corn are difficult to irrigate with sprinklers. Costs of sprinkler irrigation are affected by the availability of gravity head, the cost of power and pumps to supply the head where gravity head is not available, the configuration of the field, the cost of irrigation water, and the cost of labor to move the pipe. Sprinkler irrigation is considered the most economical method for coarse-textured soil with slopes over 1.5 per cent and for all soils with slopes over 6 per cent.

The border strip method utilizes a 30- to 60-foot wide strip with a level cross section and raised borders on the edges. The linear slope is designed to achieve a uniform rate of application throughout the border strip. The irrigating stream should contain a minimum of one second-foot for each ten feet of strip width. Except for use on row crops, the border strip method of irrigation is the most economical where the slope of the land is gentle, the soil texture is fine to medium, and sufficient water is available for the proper stream size.

Furrow irrigation is utilized for row crops where a stream can be directed between rows of plants. Some row crops such as corn can be irrigated more successfully by furrow irrigation than by any other method provided the topography is suitable. This method is the most economical for irrigating row crops except when soils are coarse-textured or land slopes exceed six per cent.

Corrugates are small corrugations or shallow furrows placed in the soil before a non-row crop is planted. They are sometimes used to irrigate before planting if natural moisture is insufficient for early plant development. This method is the most economical for non-row crops when the stream size is not sufficient for the border method of irrigation and for coarse soils with slopes less than 1.5 per cent.

The Agricultural Stabilization and Conservation Service and the Soil Conservation Service of the Department of Agriculture have programs to help the irrigators level their fields and prepare them for better irrigation systems. In addition to the above agencies, the State Extension Services are conducting classes and operating irrigated farms to instruct and help the irrigator select the most economical and efficient method of irrigation for his farm.

Water Reuse. By utilizing the wastewater or return flow from an industry, municipality, irrigated area, or other water user to supply the water requirements of additional users, the gross volume of water diverted from a river system to supply all users may be reduced. In the case of a single water user, recycling of all or a part of the wastewater can reduce gross water requirements. In the extreme case, wastewater discharge can be eliminated and gross diversions reduced to net consumptive use requirements.

The economic feasibility of water reuse is dependent upon the relative costs of treating wastewater for reuse versus the costs of providing and treating a larger raw water supply. The technical feasibility is dependent upon the availability of treatment methods, such as desalination, capable of producing suitable quality water from wastewater.

Salinity Control Effects of Water Conservation. Application of water conservation measures should result in a temporary increase in the available water supply of the Upper Basin. However, the long-term effects on supply and the availability of any supply increase for salinity control in the Lower Basin are not clear.

Reduction of consumptive use by irrigation, by phreatophytes, and in the headwaters watershed would increase the water supply available in the Upper Basin. In areas where the present supply is fully utilized, availability of additional water would probably result in new land being placed under irrigation to utilize any surplus water. This action is encouraged by the appropriate water right procedures found in many state water laws. Thus, the long-term effect of such water conservation could be no net change in the water supply available for salinity control.

Reduction of diversion requirements by water reuse or improved irrigation efficiency could have a slightly different effect on available water supply. The immediate result would be an increase in the supply available at the point of diversion. This surplus water would probably be utilized as discussed above. Increasing the irrigated area would increase consumptive use. Thus, the long-term effect of such conservation measures might actually be a decrease in water supply leaving a subbasin. It is doubtful if any increased supply of water available for salinity control would result.

Reduction of reservoir evaporation losses could potentially increase the available salinity control supply as such savings would be produced below most Upper Basin use points. However, long-term releases from the Upper Basin will probably be held to compact allotments. Thus, conserved water would probably be utilized to meet Lower Basin delivery requirements allowing increased consumptive use in the Upper Basin.

The application of conservation measures in areas receiving water exports could potentially increase available Upper Basin supply by decreasing export requirements. However, any increased supply would probably be beneficially used as discussed above, resulting in no increase in the supply available for salinity control.

In summary, under present legal constraints and traditional patterns of water utilization, the application of water conservation measures would produce few benefits as a direct result of increased water supply available for salinity control. However, such measures may be significantly beneficial in reducing salt loading as discussed in later sections. Also, if legal constraints were modified to make conserved water available for salinity control, significant benefits could result.

Water Augmentation Measures

The actual quantity of water available for use in the Colorado River Basin and its allocation among water users have been the subject of much controversy. However, it is apparent that a water shortage will exist in the basin if the water resource developments proposed by various local, state, and federal agencies are carried to completion. To alleviate this shortage, a number of water augmentation measures have been investigated. These measures include weather modification to increase Basin precipitation and various schemes to import high quality water from other river basins or from the ocean following desalination. A number of potential water augmentation measures are discussed below. Legal and institutional constraints which may limit the feasibility of such measures are discussed in Chapter VII.

Weather Modification.

Weather modification is a science still in its relative infancy. Increasing precipitation and watershed yield by weather modification are relatively new concepts. Consequently, operations in this field have not progressed significantly beyond the pilot watershed stage. However, pilot scale activities conducted for several years in California by a number of agencies including the Bureau of Reclamation have shown the technical feasibility of increasing watershed runoff by as much as ten to twenty per cent.

Research has been initiated by the Bureau of Reclamation to investigate the feasibility of augmenting Colorado River flow by weather modification. A five-year pilot program of weather modification in the Upper Basin was initiated in September 1968. Seeding of target areas will begin during the 1970-1971 winter season.

Preliminary estimates indicate that an annual watershed yield increase of as much as 1.9 million acre-feet might be obtained by a full-scale, basin-wide weather modification program. Costs are estimated to total $1.50 per acre-foot of increased yield. Results of the pilot program will allow these estimates to be verified and refined.

A full-scale program would probably concentrate on increasing snowfall in the high mountain areas of the Upper Basin. Since runoff from these areas is generally low in salinity, the increased yield would probably be low in salinity also, with significant salinity control effects resulting.

State water right laws do not provide for beneficial use of water for salinity control. Since a majority of both the weather modification and salinity control activities will be under federal control, replacement of water losses from salinity control projects with water obtained by weather modification may be practicable. An estimated cost of $2.00 per acre-foot for replacement water has been included in proposed salinity control project costs discussed in Chapter VI.

Water Importation. Traditionally, man has devised schemes for transporting water from areas of excess supply to areas of need whenever water shortages have developed. Thus, the impending water shortage in the Colorado River Basin has spawned a number of diverse and imaginative proposals for augmenting basin supply by importation of high quality water from various sources outside the basin. Ironically, it is the export of basin water to water-short areas adjacent to the Upper Basin and to southern California that has contributed to the need to augment basin supply. The need for augmenting the water supply will be further increased by construction of the Central Arizona Project. However, water compacts and other legal constraints would severely limit any reductions in these exports. Thus, means of augmenting available supply must be sought or proposed water use will be curtailed.

At least six major projects which would import water from other basins have been proposed in the past. In most cases these proposals envisage tapping rivers in the Pacific Northwest which, at present, have surplus water available.

In addition, several international water resource development schemes have been proposed which would integrate a number of river systems in Canada and the United States. Surplus Canadian water could be diverted southward by such development to a number of water-short areas including the Colorado River Basin.

Another potential source of high quality water for importation into the basin is demineralized sea water. Desalination techniques have steadily improved in recent years with concurrent reductions in unit costs of demineralized water. At present, desalination is not competitive with alternative sources of fresh water. However, it is anticipated that unit costs of demineralized water will continue to decrease as a result of continued research and development in this field.

Thus, desalination should receive further consideration as a source of import water.

The Gulf of California and Pacific Ocean are in relatively close proximity to the Lower Colorado River and to areas utilizing large amounts of Colorado River water. A proposed large-scale desalination plant located near Los Angeles has received serious concentration as a source of supplemental water supply for that metropolitan area.

The Bureau of Reclamation completed a reconnaissance study in January 1968, which indicated that it may be technically feasible to augment the Colorado River flow by approximately 2-2.5 million acre-feet annually by desalination of sea water. It is anticipated that an augmentation project of this type would be constructed in stages with the first stage starting about 1990 and the last stage completed about 2010. The addition of 2 million acre-feet of demineralized water annually to the Colorado River system at Lake Mead would decrease average salinity by approximately 130 mg/l. Under present technology, the cost of demineralized water would exceed $100 per acre-foot. Salinity control with such high cost water is not economically feasible at this time. However, the use of this water as a supplemental supply for municipal and industrial use or irrigation of high value crops may be a feasible alternative. This possibility and the effects of expected reductions in unit water costs will receive further investigation.

A related study of the potential of desalination as a supplemental water source for the Lower Basin has been conducted jointly by the United States and Mexico under the chairmanship of the International

Atomic Energy Agency. Study conclusions were similar to those discussed above.

Other Considerations. The legal and institutional constraints affecting the practicality of water augmentation measures are discussed in detail in Chapter VII. However, one special constraint warrants discussion at this point. Section 201 of the Colorado River Basin Project Act, Public Law 90-537, prohibits the Secretary of the Interior from undertaking reconnaissance surveys of proposals for importing water into the Colorado River Basin for ten years from the effective date of the Act, September 30, 1968. Thus, the feasibility of importation schemes cannot be investigated by the Secretary of the Interior until 1978.

The Act also provides that satisfaction of the requirements of the Mexican Water Treaty shall constitute a national obligation which shall be the first obligation of any water augmentation project planned pursuant to Section 201 of the Act.

MEASURES FOR REDUCING SALT LOADING

Salt is discharged to the river system from a variety of sources, both natural and man-made. The relative magnitude of the various sources were discussed in Chapter III. Man-made sources are most amenable to successful control. A number of natural sources may also be controlled. Control methods are designed to either remove the salt load from the river system at the point of discharge of the source or to reduce water flow through a source of salt pickup and thus reduce the salt contribution of such an area. Technical details of specific control measures applicable in the Upper Basin are discussed below.

Control of Natural Sources

A number of natural sources of salt existed in the basin prior to man's arrival. These sources remain relatively unchanged in magnitude by man's activities. The necessary technical knowldege is available to control some natural salt loads. However, the economic feasibility of such control has not been fully evaluated.

Natural Discrete Sources. Discrete sources encompass flow from springs, seeps, and other localized, concentrated discharges. Since such sources contribute high salt loadings from a small area, effective control may be technically feasible.

Discrete sources may be controlled by removing the entire discharge from the river system, by removing only the salt load from the system, or by preventing any discharge from the source.

A number of discrete sources discharge to small tributary streams or have well defined discharge channels. In such cases the entire discharge can be intercepted and appropriate control measures applied. The intercepted flow can be conveyed to an impoundment and confined for evaporation. This type of control effectively removes the entire discharge from the river system. Application of this method requires an adequate area for an evaporation pond which must either be impervious or located in a geologically closed basin. Also, annual precipitation must be less than average annual evaporation. Such impoundments may be developed and managed for recreation, wildlife habitat, or other beneficial uses. One drawback to this method is that evaporation losses in the basin are increased. Another drawback is that a catastrophic event could return the salt to the river system. Thus, this method should be utilized for moderate to highly mineralized discharges or no net reduction in salinity will occur.

Small sources of highly concentrated brines may be controlled by subsurface disposal. This method is feasible only if suitable geological formations are available to confine the brine and prevent any return flow to the river system.

Demineralization of the collected discharge is an effective means of removing the salt load from the river system with only a small depletion of water discharged by the source. However, two factors limit the feasibility of demineralization. Concentrated brines resulting from this process must be disposed of by one of the two methods discussed above. The most serious limitation is the lack of an economically feasible method of demineralization for the small discharges contributed by discrete sources.

In a few cases mineral springs may be the outlet for an aquifer confined by impermeable boundaries on all sides. It may be technically feasible to plug the aquifer outlet or to apply hydrostatic pressure to suppress aquifer outflow. Such action could completely eliminate the discharge and salt load from this source. However, a more probable result would be that, following a period of adjustment, the same volume of flow would reappear at some higher elevation near the aquifer recharge area. In this case the discharge would probably have a much lower salinity. Thus, the salt load would be reduced with little or no loss of aquifer yield.

Natural Diffuse Sources. Over half of the salt load discharged to the Upper Basin river system is obtained by surface runoff and groundwater inflow from diffuse sources. Surface runoff picks up salts as it passes over the surface of the soil and salt-bearing formations. Additional salt is believed to be picked up from sediments carried in suspension by streams. Groundwater picks up salt as it percolates through the soil profile and moves through aquifers. Methods of controlling diffuse sources are thus designed to reduce the opportunity for surface runoff and groundwater to leach or dissolve minerals from soil and underlying geological formations.

Salinity contributions from natural runoff may be decreased by various measures aimed at reducing the extent and amount of water infiltration in areas of high salt pickup. For example, contour ditches might be constructed to intercept runoff and carry it rapidly into the stream, and surface sealants might be used to control the percolation of surface waters into the soil profile. In local areas where salt is picked up from formations crossed by the stream channel, it may be possible to construct an impervious channel or a bypass channel to prevent contact of water with the saline formation.

Highly mineralized groundwater is discharged by aquifers in some areas. By utilizing similar diversion or surface sealing techniques to reduce the recharge of the aquifer, displacement of this saline groundwater could be reduced with resulting reductions in salt load discharged to the system.

Percolation of water into the alluvium and shallow groundwater underlying river valleys exposes water to the underlying formations (much like the percolation of irrigation return flows). Reducing the underground movement of water should, in most cases, reduce the loading of salts derived from valley soils and underlying formations.

Sediment swept into the stream from sheet and channel erosion is weathered by continued exposure to well aerated water and by persistent turbulent mixing. The amount of salt contributed from this source is not known. Numerous erosion control measures have been developed for land protection but little is known about how they affect salinity. Additional study of sediment-salinity relationships will be required to devise effective control techniques.

All of the control methods discussed above involve some form of modification of the movement of surface or groundwater. Flood control, wildlife habitat, and water rights are just a few of the various factors that must be carefully evaluated before such modifications are carried out.

Control of Man-Made Sources

Man has increased the salt burden carried by the river system by producing municipal and industrial wastes and by heavy utilization of water for irrigation. Since man has control of such water use, these sources of salt can be more completely controlled than natural sources.

Municipal and Industrial Sources. Municipal wastes are generally relatively low in salinity. These salt sources can be effectively eliminated by lagooning and evaporation of the wastes, injection into deep formations, or discharge into closed basins.

With the exception of oil field brines and uranium mill effluents, industrial wastes are also relatively low in salinity. Industrial wastes may be controlled in the same manner as municipal wastes.

Due to their low salinity, the loss of water produced by eliminating discharges of municipal and industrial wastes would in most cases offset decreases in basin salinity produced by removing these salt sources. Also, since the salt load from these sources is a small fraction of total basin salt burden, complete control of municipal and industrial discharges would have little effect on basin salinity problems. Thus, salinity control measures should be applied to only the most concentrated sources.

A specialized industrial source which, if not controlled, could produce significant salinity increases is oil field brines. However, about 97 per cent of the salt derived from this source is re-injected into subsurface formations or discharged to lined evaporation ponds. Similar control techniques can be applied to new wells.

Several abandoned oil wells flow highly mineralized water much like natural springs. For this reason, these salt sources have been considered natural sources in a number of salt loading inventories. Flowing wells can frequently be controlled by plugging the casing with concrete. Alternatively, the discharge can be disposed of in the same manner as natural spring flow.

Irrigation Return Flows. Irrigation contributes an increased salt load to the river system in a number of different ways. When new land is brought under irrigation, any highly soluble salts present in the soil are leached out by the irrigation water in a relatively short period of time. As irrigation continues, additional salts are dissolved from the soil. These dissolved salts are picked up by any excess irrigation water and returned to the river system as surface wastewater or as groundwater flow. This pickup of salts from the soil by return flows may continue for many years.

The major portion of return flows usually percolates downward into the groundwater aquifer and then moves horizontally either into drains or to the river system. If the groundwater is highly saline, the return flows may displace large volumes of the saline groundwater with resultant large salt loads entering the river system. The return flows may also pick up significant salt loads from aquifer materials or underlying formations if sufficient soluble salts are present in these locations.

Wastewater from inefficient irrigation may flow onto or under adjacent non-irrigated land. Evaporation from such lands may concentrate salts drawn to the surface by capillary flow into a surface crust which is easily removed by surface runoff. Thus, irrigation may indirectly contribute to salt pickup from non-irrigated lands.

Salt loads contributed by irrigation may be controlled by the proper selection of land to be irrigated, by reducing return flows to a minimum, and by intercepting return flows for treatment or disposal. Specific control measures are detailed below.

> Land Selection. Many soils within the Colorado River Basin contain high concentrations of soluble salt. Irrigation of these soils results in high salt pickup by return flows during the initial leaching period. Large salt loads are also contributed by the irrigation of shallow soils overlying highly saline shales. Classification of all lands in the Basin would allow identification

of these problem soil areas. Cessation of irrigation of shallow soils overlying shale would lower the Basin salt burden. The Fact Finders Act of 1924 required that land to be served by Bureau of Reclamation projects be classified to determine its suitability for irrigation. Soils with high saline concentrations or shallow soils overlying highly saline shale are classified as unsuitable for irrigation by Bureau of Reclamation projects. Thus, additional saline soils will not be brought under irrigation by Bureau projects. Similar restrictions on new private development would eliminate increased irrigation of saline soils.

Classification of the lands in the Emery County Project in East Central Utah showed that about 6,500 acres of the existing irrigated area had shallow soil overlying highly saline shale. These lands have a water right prior to the Emery County Project water right and are still being irrigated. It may be possible to purchase water rights or the land and water rights and discontinue irrigation of some of these shallow soils.

Major problems associated with purchase of this type of land would be the disruption of the owner's farm operation and the transfer of water right to other land or other uses. Some state water laws prohibit separating the water right from the land or transfer or sale except for higher classified uses.

Additional investigations and research are needed to determine the salinity control benefits of this type of project.

Canal Lining. Many of the early irrigation canals constructed by private interests are still in use. Seepage losses from these canals are frequently large. In addition, seepage losses from modern canals may be relatively high in various limited areas where pervious materials were encountered. These seepage losses contribute to the volume of return flows which pick up salt from groundwater aquifers. Thus, reducing seepage would reduce the salt load of return flows in such cases.

Seepage losses also occur from farm ditches and distribution systems. In some areas canals are kept full during the non-irrigation season to provide livestock water. Providing enclosed or pipe distribution systems would reduce farm seepage losses. A pipeline system for winter livestock water supply would eliminate the need for maintaining flow in the canals year around.

Except for some areas where high value crops are grown, relatively little canal lining or construction of pipe distribution systems has been accomplished in the Upper Basin. Thus, potentially large reductions in return flows could be achieved by such construction.

Improved Irrigation Efficiency. Low irrigation efficiencies result in excess return flows. Thus, improvement of irrigation efficiencies, as discussed in a preceding section on water conservation, would reduce the volume of return flows and reduce salt loads in the same manner as reducing canal seepage losses.

Drainage. Open surface drains and underground pipe drains have been constructed in a number of irrigated areas. These drains were usually provided to lower natural high water tables or to reduce waterlogging by irrigation return flows. To reduce costs, drains were usually constructed as deep and as far apart as soil conditions would allow. Such practices result in long flow paths for return flows.

By constructing closely spaced shallow drains, salt loads can be reduced by shortening the flow paths of return flows. Also, shallow drains can reduce the deep displacement of saline groundwater. Additional research is needed to determine optimal drain spacing and depths for various soil conditions.

Construction of surface drains to intercept surface runoff and irrigation tailwater can reduce the pickup of salt from non-irrigated land.

Interception of Return Flows. Irrigation return flows reach the river system by a variety of routes. Much of the flow may occur as increased groundwater discharge spread over a wide area. In such cases interception of return flows may be difficult. However, return flows may be collected by drains or small tributaries and concentrated into a single stream that may be easily intercepted and conveyed to a treatment or disposal facility.

Once collected, irrigation return flows may be controlled in the same manner as mineral spring discharges. Evaporation, desalination, and subsurface injection into geologically closed formations are effective, technically feasible control methods. However, the practicality of utilizing these control methods for return flows is limited by the same factors as discussed in the section on mineral springs.

CHAPTER VI. STATUS OF SALINITY CONTROL ACTIVITIES IN THE UPPER BASIN

Preceding chapters have described the causes and effects of salinity and the technical possibilities for salinity control. In effect, the "state of the art" with respect to salinity control knowledge was described. This chapter discusses the current status of the application of such salinity control knowledge in the Upper Basin.

The information presented in the preceding chapters was assembled from available data and from reconnaissance survey results. A substantial portion of the study budget was expended in defining and assembling this information on the current "state of art." Additional results of the study are detailed below.

As originally envisioned, the objective of this initial cooperative study was to develop a reconnaissance-grade salinity control plan for the entire Upper Basin. The study report was to contain the following items: a summary of the causes and effects of salinity including a complete inventory of identifiable salt sources, a summary of technically feasible salinity control methods, preliminary designs and cost estimates for various types of salinity control projects, an analysis of the effects of salinity control on basin water supply, an economic analysis presenting relative benefits and costs of the control plan, an analysis of legal and institutional constraints affecting the plan, a financing scheme for funding necessary investigations and construction, and, finally, a summary of specific salinity control projects recommended for inclusion in a feasibility study to secure authorization for construction of salinity control measures.

Many of the originally scheduled activities have been completed. However, budget and time constraints prevented meeting all objectives of the study. Early in the study it became evident that many factors necessary for formulating an effective salinity control program were either unknown or poorly defined. Research would be needed in some cases to better define processes affecting salinity concentrations. The practicality of certain salinity control measures would need to be demonstrated by field-scale installations before their relative benefits and costs could be assessed. Thus, it became evident that a much larger expenditure of time and funds than originally envisioned would be required to formulate an effective salinity control program for the entire Upper Basin. Perhaps the most significant study result, however, was the identification of the relationship between salinity control in the Upper Basin and salinity detriments in the Lower Basin. The need for a coordinated salinity control program encompassing the entire Colorado River Basin was evident.

Considering the present status of salinity control knowledge and the legal and institutional setting of the Colorado River Basin, a basin-wide salinity control program should be conducted in two phases which can be described as a planning phase and an implementation phase. The planning phase would require a substantial expansion of present research, demonstration and technical investigation activity along with evaluation of legal, institutional and financial factors. The objectives of the planning phase should be to develop the necessary salinity control technology, to formulate alternative salinity control plans to meet possible alternative salinity management objectives, and to evaluate the costs, benefits, allocation of costs, institutional and legal constraints, and financing schemes associated with such alternative plans.

The second or implementation phase of the program would seek to achieve a measure of actual control of salinity by selection and implementation of a plan developed by the planning phase. Objectives of the second program phase should include establishment of the institutional framework for plan implementation, selection of final program objectives and the associated alternate salinity control plan, implementation of the plan, and long-range management of salinity.

A number of research, demonstration, and technical investigation activities have been completed or are under way which will provide valuable input to the planning phase of a basin-wide salinity management program. Several salinity control measures have been placed in operation in the Upper Basin. Cost and feasibility data have been collected on a number of other control measures. These activities are illustrated in Figure 5 and are discussed in greater detail below. For convenience, the discussion has been divided into sections by type of salt source.

CONTROL OF NATURAL DIFFUSE SOURCES

Diffuse sources contribute the largest salt load to the river system. Unfortunately, these sources are also the most difficult to control. Knowledge of basic processes controlling salt contributions is limited. Thus, few proposals for control of diffuse sources have been investigated to date.

Very little information is available on the relative salinity contribution of sediments. A fundamental study of sediments as a

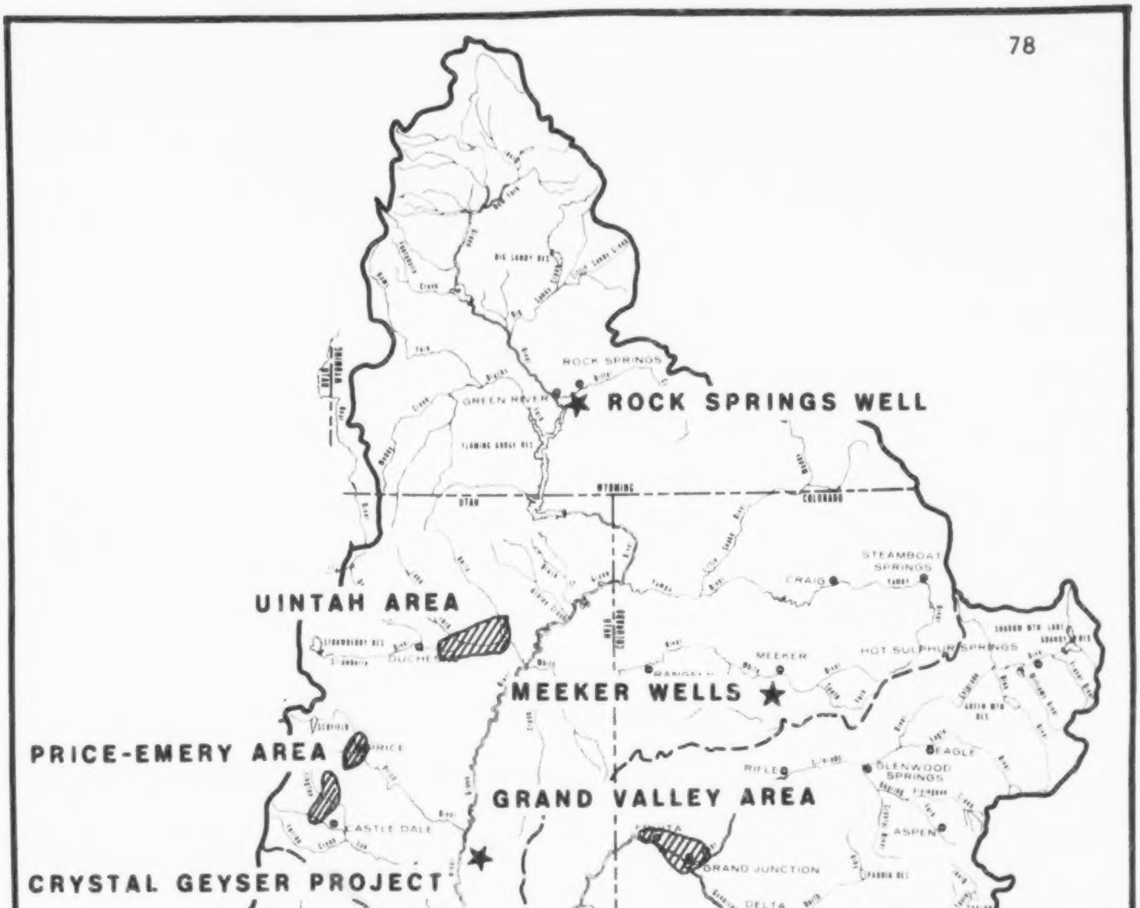

ROCK SPRINGS
GREEN RIVER
ROCK SPRINGS WELL
WYOMING
UTAH
COLORADO
CRAIG
STEAMBOAT SPRINGS
UINTAH AREA
DUCHESNE
MEEKER
HOT SULPHUR SPRINGS
MEEKER WELLS
SCOFIELD
PRICE
PRICE-EMERY AREA
RIFLE
GLENWOOD SPRINGS
EAGLE
GRAND VALLEY AREA
CASTLE DALE
ASPEN
GRAND JUNCTION
CRYSTAL GEYSER PROJECT
DELTA
UNCOMPAHGRE AREA
MOAB
MONTROSE
LYMAN
URAVAN
NATURITA
PARODOX PROJECT
TELLURIDE
OURAY
SILVERTON
ESCALANTE
RICO
CORTEZ
DURANGO
MEXICAN HAT
ARIZONA
NEW MEXICO
GLEN CANYON DAM
FARMINGTON

Figure 5. Location of Salinity Control Investigations in the Upper Colorado River Basin

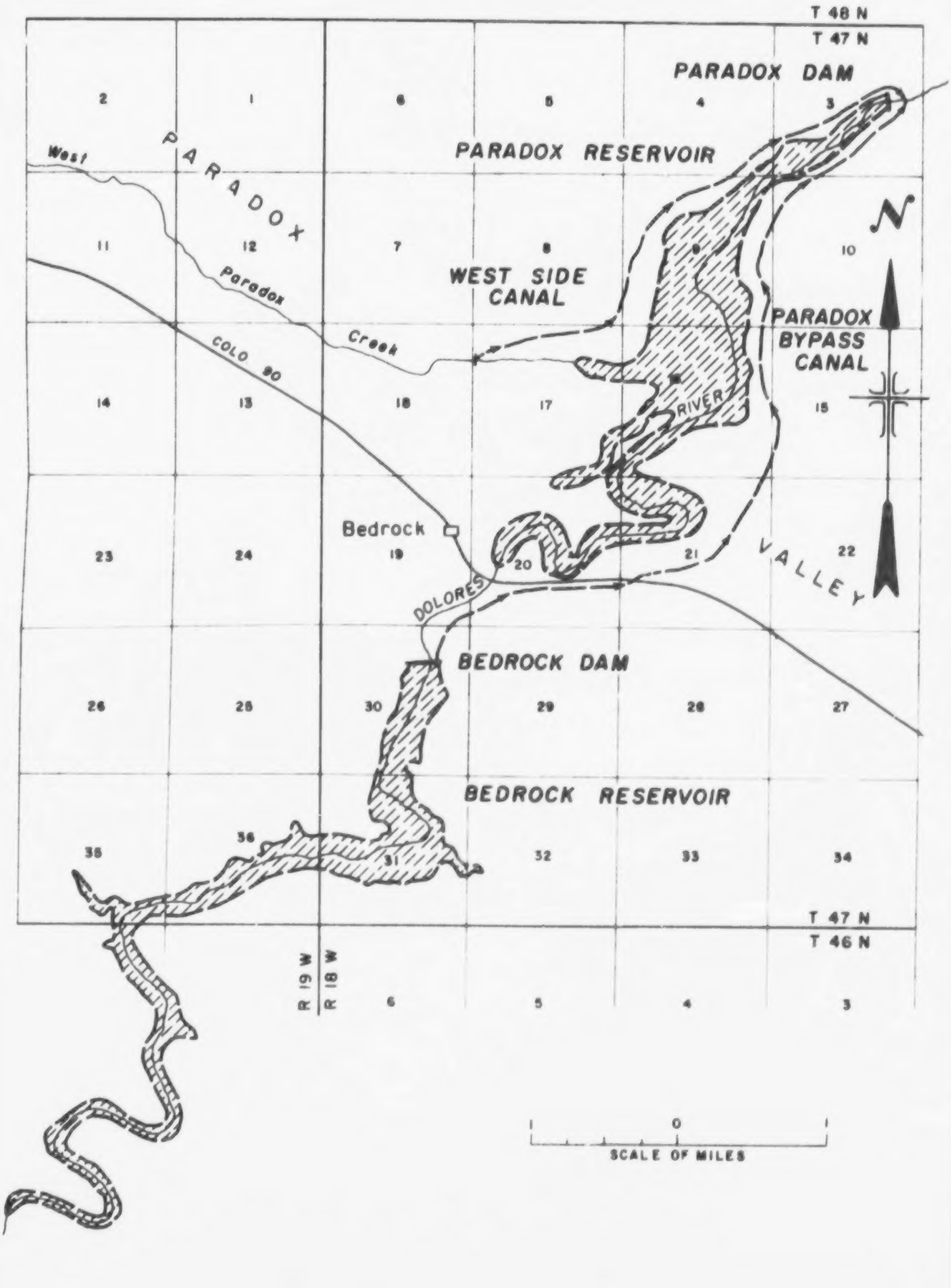
source of salinity will be conducted in the future. If warranted, a demonstration project will also be undertaken.

The salinity effects of ground water movement as separated from irrigation return flow effects are not well defined. Several research proposals in this field are under review. A research project to investigate groundwater effects should be initiated in the near future. A demonstration of the salinity control effects of modifying groundwater movement may also be desirable.

The Dolores River has been identified as one of the tributaries contributing relatively high salt loads to the river. A large portion of this salt load (estimated to be 230,000 tons per year) is picked up in a four-mile reach as the river crosses Paradox Valley. The large salt load contributed by this small area indicated that control of this source was potentially feasible. The Bureau of Reclamation has investigated this source and has completed a plan formulation grade design of a salinity control project. Details of the proposed Paradox Salinity Control Project follow.

Paradox Salinity Control Project

The Paradox Salinity Control Project (Figure 6), consisting of Bedrock Dam and Regulating Reservoir, Paradox Dam and Evaporation Reservoir, Paradox Bypass Canal, and West Paradox Creek Diversion Canal as described below, is a potentially feasible project designed to eliminate an estimated 230,000 tons of salt contributed annually to the Dolores River. However, as designed, this project has a risk factor in that it only provides for regulating the flow of a 100-year flood. A flood with a ten-day volume greater than that of the 100-year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T 47 N
PARADOX DAM
PARADOX RESERVOIR
West
PARADOX
Paradox
Creek
COLO 90
WEST SIDE CANAL
PARADOX BYPASS CANAL
RIVER
N
Bedrock
DOLORES
VALLEY
BEDROCK DAM
BEDROCK RESERVOIR
T 47 N
T 46 N
R 19 W
R 18 W
2
1
6
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SCALE OF MILES

Figure 6. Location of Parodox Salinity Control Project

flood would cause a flow through the Paradox Evaporating Reservoir which would wash a part of the retained salt into the Colorado River system. A flood approaching the volume of the design flood would probably wash nearly all of the retained salt from the evaporating reservoir. Construction of a bypass canal and regulating reservoir of sufficient capacity to control the design flood (i.e., a 5,000-second-foot bypass canal and a 220,000-acre-foot reservoir), thus eliminating the risk of salt washout, is not justified by the salinity control benefits.

An alternate plan to the regulating and evaporating reservoirs would be to provide a lined bypass canal of sufficient size (i.e., 5,000 second-feet) to carry the high flows of all but the wettest years. This would prevent most of the Dolores River flows from flooding the salty soil and rock formations adjacent to the river, dissolving the salt, and carrying it back to the river during low flows. The alternate plan could reduce but not eliminate the 230,000-ton salt load picked up annually by the Dolores River as it crosses Paradox Valley. Construction costs and resulting benefits have not been estimated for such a project.

Additional hydrologic, groundwater movement, and water quality data would be required to evaluate the feasibility of the alternative plan and the significance of the risk factor described above. Additional studies of this area will be made in order to select the best method of salinity control. Details of the present project design are discussed below.

The 48,000-acre-foot Bedrock Regulating Reservoir would regulate the Dolores River flows, including the flow of a 100-year flood, for conveyance through Paradox Valley by the 1,500-second-foot Paradox Bypass Canal.

The 100-second-foot West Paradox Diversion Canal would divert West Paradox Creek flows around the Paradox Evaporating Reservoir. The Paradox Evaporating Reservoir with an area of 1,000 acres would evaporate an estimated 3,000 acre-feet of saline underground inflow occurring in Paradox Valley.

Paradox Valley is a northwest-southeast trending anticlinal structure formed by plastic flowage of salt in the underlying Paradox formation. Subsequent erosion has exposed the salt and gypsum beds. Oil test wells indicate the Paradox formation underlying the valley is about 10,000 feet thick and composed of 75 per cent salt and gypsum. The groundwater adjacent to the Dolores River and thought to be recharged primarily from the high flows of the river has a salinity concentration of about 25,000 parts per million. Wells have exposed a deeper brine with a concentration of 270,000 parts per million.

The climate in the area is variable, but in general it is temperate and semiarid. Precipitation ranges from less than 10 inches at the lower elevations to over 30 inches in the mountainous sections. The temperature in Paradox Valley ranges from below zero to over 100°F., with a mean annual temperature of 45-50°F. The evaporation averages about 36 inches per year.

Designs and estimates are of plan formulation grade and are based on a field inspection of the sites; USGS quadrangle maps, scale 1:24,000; contour interval, 20 feet; and USGS surface geology maps.

Bedrock Dam and Regulating Reservoir. Bedrock Damsite is located on the Dolores River (Figure 6) about 0.8 miles upstream from Colorado Highway 90 near Bedrock, Colorado. The dam would be a rolled earth, sand, gravel, and cobble fill structure with a height of 135 feet above the streambed and a crest length of about 1,300 feet. A cutoff would be excavated to bedrock and the foundation grouted. The upstream slope would be 3:1 and the downstream slope 2:1.

An adequate supply of both tight and free draining earth materials appears to be available near the construction site. Riprap could be obtained from the harder sandstone cliffs bordering the construction site. Should this material be unsatisfactory, riprap could possibly be obtained from a limestone member of the Hermosa formation within about 5 miles of the damsite.

The construction site has not been inspected by a geologist, but appears suitable for an earthfill dam and reservoir. The lower abutments are located in an area of alluvium consisting mostly of talus from the high canyon walls. The Chinle formation is exposed higher on the abutments and the Moenkopi formation would probably be at shallow depth under the streambed. The beds dip upstream and a tight cutoff should be possible. The damsite is upstream from a faulted area shown on the USGS geology maps.

A 1,500-second-foot outlet for releases to the Paradox Bypass Canal would be located in the right abutment. A 93,000-second-foot uncontrolled, 290-foot wide, ogee concrete spillway would be located on the left abutment. The concrete chute and stilling basin would be about 800 feet long. A surcharge of 20,000 acre-feet, in combination with a spillway capacity of 93,000 second-feet and outlet works capacity of 1,500 second-feet, would provide protection against an inflow design flood having a peak of 110,000 second-feet and a 10-day volume of 300,000 acre-feet. Twenty feet would be the maximum depth over the spillway crest for the design flood.

Approximately 360 acres of privately owned rangeland and 2,165 acres of public domain land would be required for the dam and reservoir. An unimproved, jeep-type road would be relocated to provide access to private lands along the Dolores River above the reservoir. The reservoir area would require only a negligible amount of clearing.

The dam and reservoir would provide regulation of the Dolores River for conveyance through Paradox Valley by Paradox Bypass Canal. The reservoir would be operated empty except when the flow of the Dolores River exceeded 1,500 second-feet and immediately after while the reservoir was being emptied. The active capacity of 48,000 acre-feet would regulate a 100-year frequency flood having a peak of 24,000 second-feet and a seven-day volume of 75,700 acre-feet. No capacity would be provided for sediment deposition since runoff would be routed through the reservoir as rapidly as possible resulting in a low-trap efficiency. Because of the heavy sediment inflow, the cost of constructing an inactive pool for recreational use would probably be greater than the benefits.

Paradox Dam and Evaporating Reservoir. Paradox Dam would be located on the Dolores River about five miles downstream from the proposed Bedrock Dam and about one mile below Paradox Valley (Figure 6). The dam would be a concrete overflow section with rolled earth abutments. The overflow section would have a height of 25 feet above the river bottom and a crest length of 380 feet. The earth abutments would have a height of 45 feet above the river bottom and the dam would have a total crest length of about 600 feet. A cutoff would be excavated to bedrock and the foundation grouted.

An adequate supply of earth material and gravels and sand for construction of a low dam is within reasonable haul-distance of the construction site. Riprap would be available from the same source as for Bedrock Dam.

The proposed construction site has not been inspected by a geologist but appears to be suitable for a low dam. The site is located in alluvium and talus slopes of the Dolores River Canyon. Bedrock is exposed in the stream channel immediately downstream of the proposed axis. The dam foundation would be in the upper part of the Cutler formation or lower part of the Moenkopi formation. The beds dip downstream at the damsite, however, it is assumed that grouting will provide a water-tight reservoir.

Water would never be released from the reservoir under proposed operations. For emergencies, however, a small outlet works would be included.

With a 15-foot depth over the crest, the overflow section would have a capacity of 85,000 second-feet which, in combination with a surcharge capacity of 23,000 acre-feet, would provide protection against an inflow design flood having a peak of 93,000 second-feet and a ten-day volume of 270,000 acre-feet.

Approximately 420 acres of public domain and 2,300 acres of privately owned land would be required for Paradox Dam and Evaporation Reservoir. Of the private land, about 140 acres are irrigated cultivated, 990 acres are irrigated pasture and meadow, and 1,170 acres are unimproved rangelands.

Some trees bordering the Dolores River in the reservoir area would require clearing.

A short section of Colorado Highway 90, a power line, and a telephone line would be relocated around the reservoir. A section of an unimproved county road from Colorado Highway 90 to the Paradox Dam would be relocated to the operation and maintenance road on the berm of Paradox Bypass Canal. A brine well in the reservoir area is supplying 270,000 parts per million water to a uranium mill at Uravan, Colorado. It will be necessary to protect this well or provide another source of brine for the mill.

Paradox Dam and Reservoir would trap and contain the saline return flows and part of the runoff of Paradox Valley and prevent the salt from continuing downstream. No downstream releases would be made from the reservoir and inflow would be offset by evaporation of about 3,000 acre-feet annually.

Paradox Bypass Canal. The Dolores River flows would be routed through a 5.7-mile-long, 1,500-second-foot, concrete-lined bypass canal around the proposed Paradox Evaporating Reservoir and returned to the river channel below Paradox Dam through a baffled apron drop. The canal was routed around the right side (east) of the reservoir to avoid the return flows from the irrigated land west of the proposed evaporating reservoir.

West Paradox Creek Diversion Canal. The West Paradox Creek low salinity flows would be diverted through a 4-mile-long, 100-second-foot, unlined canal around the proposed Paradox Evaporation Reservoir and dropped into the Dolores River below the proposed Paradox Dam through a baffled apron drop (Figure 6). High salinity flows would flow into the proposed evaporating reservoir. The diversion canal would not be lined because divertible flows occur only for short periods resulting from snowmelt and heavy summer rainstorms and the volume of the seepage losses probably would not justify the cost of lining the canal.

Hydraulic properties of the canals are:

	Q cfs	A sf	V f/s	S	B ft.	D ft.	fb ft.	s:s
Paradox Bypass Canal	1,500	282.9	5.30	.00025	20	8.6	3.0	1.5:1
West Paradox Creek Diversion Canal	100	50.1	2.02	.0003	8.0	3.7	2.3	1.5:1

Estimated cost--The reconnaissance construction and engineering cost estimated for the Paradox Salinity Control Project is 16 million dollars. Details of the estimated costs are as follows:

Bedrock Dam and Regulating Reservoir	$10,000,000
Paradox Dam and Evaporating Reservoir	2,800,000
Paradox Bypass Canal	3,000,000
West Paradox Creek Diversion Canal	220,000
Total construction and engineering cost	$16,020,000
Annual OM and R	30,000
Colorado River stream depletion replacement (3,000 acre-feet at $2 per acre-foot per year)	6,000

CONTROL OF NATURAL DISCRETE SOURCES

Potential methods for controlling discrete salt sources are better defined than those applicable to diffuse sources. However, local conditions may limit the technical feasibility of applying such methods in the Upper Basin. Also, economic feasibility of control has not been demonstrated.

The Bureau of Reclamation has investigated the feasibility of controlling several of the larger mineral springs. To date, no feasible projects have been formulated.

Two large spring areas--Dotsero and Glenwood Springs--contribute over 90 per cent of the salt load discharged by discrete sources to the main stem of the Colorado River in the State of Colorado. The springs emerge as numerous small and medium-sized springs rather than as two large discharges. The springs appear to issue from the Leadville limestone which outcrops in the area. Discharge points are located along both sides of the river and under the water surface. The source of recharge is believed to be the White River Plateau about 20 miles to the north.

Surface discharge of the Dotsero Springs is estimated to be approximately 6.5 second-feet with an average salinity concentration of 10,700 mg/l. The U. S. Geological Survey has estimated a total contribution from both surface and underwater springs of 17 second-feet based on the above average salinity concentration and a computed annual salt load increase of 182,600 tons in the Colorado River reach from Dotsero to Shoshone power plant.

In the Glenwood Springs area, Yampa Spring has an average flow of about 6.5 second-feet and a salinity concentration of 18,900 mg/l. Many of the other surface springs in the area exhibit the same average salinity concentration. Based on this average salinity concentration and the computed salt load increase in the adjacent river reach, the total contribution from the springs is estimated to be 18 second-feet.

It is estimated that about six second-feet of the Dotsero Springs flow and over seven second-feet of Glenwood Springs flow could feasibly be intercepted on the surface for demineralization or disposal. Most of the remaining flow at each spring area emerges under the stream surface and would be difficult and expensive to intercept.

Disposal of intercepted flow by evaporation is not feasible as there is insufficient area for evaporation ponds at or near spring locations. Lack of evaporation pond sites for brine disposal also eliminates desalination as a feasible control method. Should brine disposal be available, it is doubtful that an economically feasible desalination plant of this scale could be provided.

The potential disposal of spring flows by injection into deep, confined geological formations was not investigated. The feasibility of this control method and control of other springs will be investigated in future studies. Should feasible control plans be formulated, a demonstration project will be constructed.

CONTROL OF FLOWING WELLS

Salt loads contributed by flowing abandoned oil wells are minor with respect to total basin salt burden. However, since some of these wells discharge highly mineralized water to the smaller tributaries, elimination of such discharges can produce significant local effects as well as a reduction in basin salt burden. Also, wells are relatively easy to control in most cases.

Two flowing wells located in the White River Basin near Meeker, Colorado, were identified as the source of a total of 62,500 tons of salt per year, approximately 15 per cent of the salt load of the White River at the Colorado-Utah border. These two wells were plugged in 1968 as a demonstration of the feasibility of controlling such sources. Funds for the demonstration were provided by the FWPCA. The Bureau of Reclamation prepared specifications and supervised the plugging by a private contractor.

Costs for plugging the two wells totaled $40,000. It is estimated that the present worth of total benefits which will accrue to Colorado River water users is approximately $5 million.

Water quality in the White River downstream from the plugged wells has substantially improved. Water quality surveillance will be maintained to assess the long-term effects of eliminating these salt discharges.

The two wells previously discharged about 2,380 acre-feet of mineralized water. It is the opinion of the Bureau of Reclamation's Region 4 geologist that the flow from the plugged wells will return through natural springs near the recharge area with improved quality but no decrease in the annual discharge of the White River.

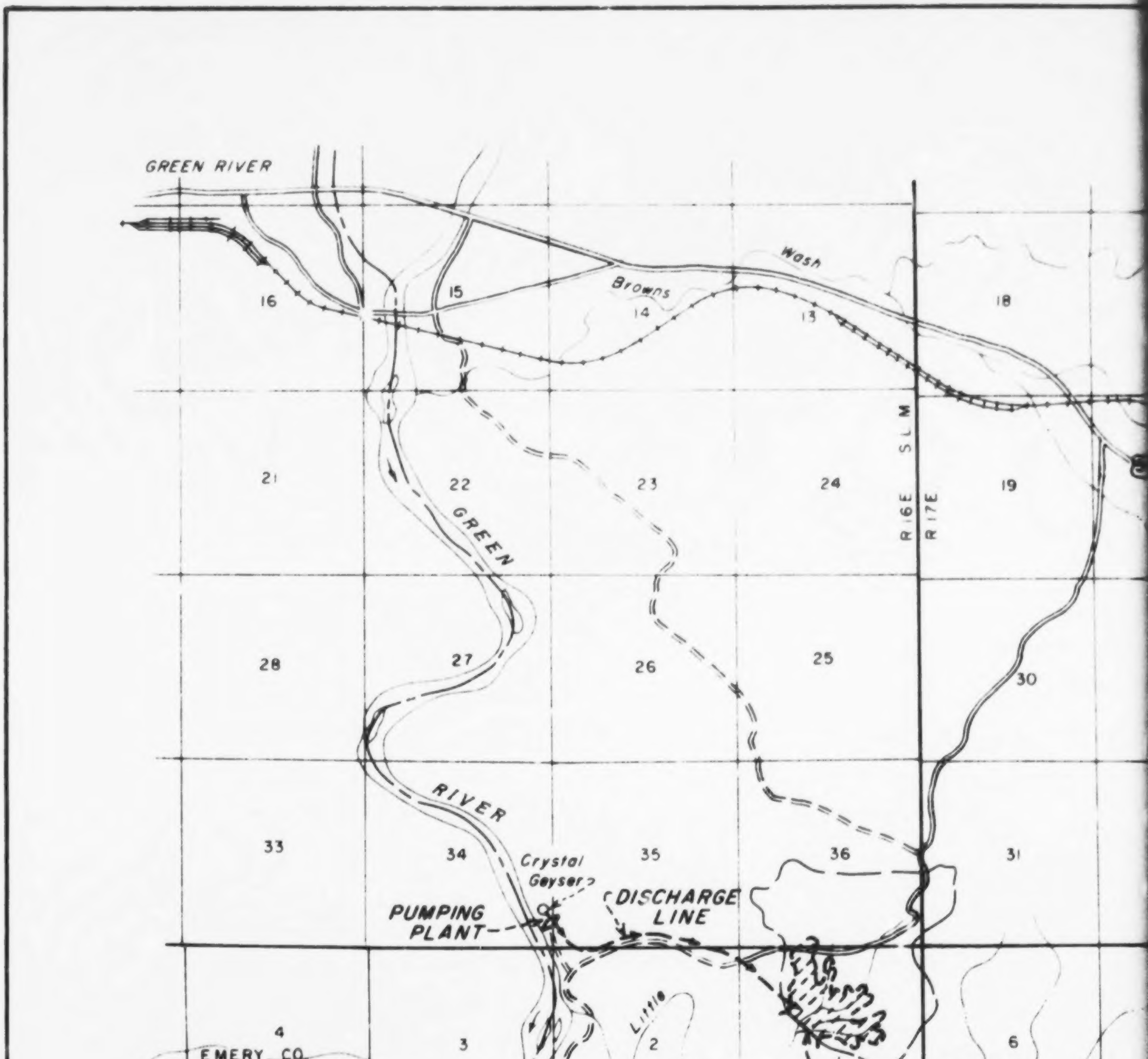
Another flowing well near Rock Springs, Wyoming, which contributed approximately 5,000 tons of salt annually, was plugged in November 1968 under the direction of the Wyoming State Engineer. The effects of eliminating this salt source have not been evaluated.

The Bureau of Reclamation has investigated the feasibility of controlling an abandoned well near Green River, Utah. A salinity control plan has been formulated and is presented below.

Crystal Geyser Salinity Control Project

Crystal Geyser, an abandoned oil test well, is located on the Green River about five miles south of Green River, Utah (Figure 7). Crystal Geyser results from a gas accumulation blowing water out of the well. Eruptions occur at about four-hour intervals. The computed yearly discharge based on the measurement of several eruptions is 204 acre-feet or an average flow of 0.28 second-feet. The geyser contributes about 3,700 tons of dissolved solids per year to the Green River.

The recreational potential of the geyser should be investigated. Local groups now use the site as a picnic area. The owner has stated that he would like to develop the geyser site as a tourist attraction. However, such development may not be practical due to the relatively long period between eruptions, the distance from the main highway, and the lack of other developed tourist attractions in the area.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27
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RIVER
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36
31
Crystal Geyser
PUMPING PLANT
DISCHARGE LINE
Little
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3
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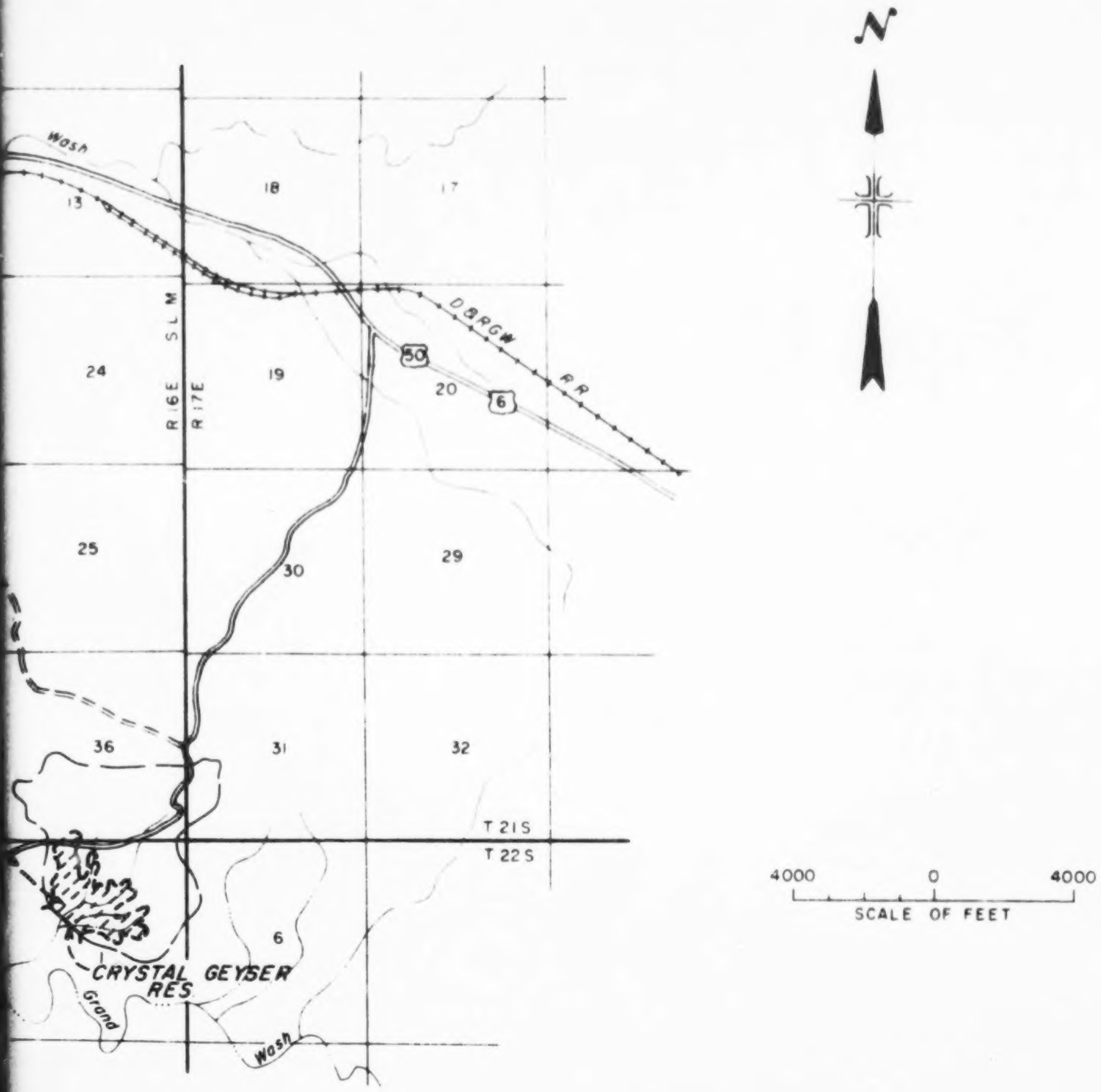
EMERY CO
GRAND CO
CRYSTAL GEYSER RES
Grand
Wash

Figure 7. Crystal Geyser Reservoir Site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CRYSTAL GEYSER RES.
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SCALE OF FEET

Reservoir Site

Crystal Geyser is located about 200 feet north of, but does not intersect, the Little Grand Fault which extends northwest and southeast from the geyser. The property owner, however, said that several years ago small eruptions occurred in the river channel when the geyser erupted.

Two alternatives for controlling the salt load from the geyser, plugging and evaporation, were considered in the initial investigations. Because of the geyser's present use and potential development, and also because of some geologic unknowns, plugging of the geyser was not further investigated. However, a plan was formulated for a small reservoir to evaporate the geyser's discharge. The feasibility studies should investigate the possibility of plugging the geyser.

Crystal Geyser Project would consist of a 710 acre-foot evaporating reservoir, a one-half-second-foot pump and discharge line, and a 55,000-gallon equalizing reservoir.

Designs and estimates are of plan formulation grade and are based on a field inspection of the sites; USGS quadrangle maps, scale 1:24,000; contour interval, 40 feet; and reconnaissance surveys and topography of the reservoir and structure sites.

Crystal Geyser Dam and Evaporation site is located on a minor tributary of Little Grand Wash about 5 miles southeast of Green River, Utah, and approximately one and one-half miles from Crystal Geyser. The dam would be a rolled earthfill structure with a height of 34 feet above the streambed and a crest length of about 1,400 feet. The upstream slope would be 3:1 and the downstream slope 2:1. The upstream face would be protected with soil cement or riprap.

An adequate supply of suitable embankment materials appears to be available near the damsite. The nearest source of good quality riprap would probably be about 75 miles away, near Price or Moab, Utah.

The construction sites have not been inspected by a geologist but appear suitable for the proposed structures. Bedrock at the reservoir and damsite is the Tununk member of the Mancos shale. Overburden consists of clay material weathered from the underlying shale and is highly impermeable. Bedrock at the pumping plant and equalizing reservoir site is shale of the upper Morrison formation. Overburden consists of alluvial stream deposits and clay material weathered from the underlying shale.

Annual sediment production for this area from the Geological Survey Circular No. 256, entitled "Sedimentation in Small Reservoirs on the San Rafael Swell, Utah," dated 1953, by Mace and King, is estimated at 2.6 acre-feet per square mile or about 2.2 acre-feet per year for the 0.84-square-mile drainage area. For 100 years at this rate, 220 acre-feet of the 470-acre-foot capacity would be used for sediment storage.

The estimated average annual rate of evaporation is 3.6 feet. At this rate, 57 surface acres are needed to evaporate 204 acre-feet per year. Most of the evaporation occurs during the summer period of May through October. The evaporation rate also varies from year to year and there may be some carryover from a cool or wet year. An estimated 150 acre-feet of the storage could be needed for storage of the winter flows and carryover for evaporation during a warm summer period.

Salt would probably start precipitating out after about 20 years of evaporation and for a 100-year period would precipitate from 90 to 100 acre-feet of salts.

To prevent the salt brine contained in the evaporation reservoir from returning to the Green River, it is imperative that no spills occur from the reservoir. Therefore, in addition to the 470-acre-foot capacity for sediment storage, evaporation storage, and salt storage, storage would be required for a 240-acre-foot design flood (6-hour volume for a 0.84-square-mile drainage area).

The reservoir would be designed for a total capacity of 710 acre-feet including 220 acre-feet for sediment storage, 100 acre-feet for salt storage, 150 acre-feet for evaporation storage, and 240 acre-feet for flood storage. An area of 57 acres for evaporation would be provided at a capacity of 470 acre-feet. No outlet works would be provided and only an emergency spillway would be provided.

A one-half-second-foot capacity pump with an 8,800-foot-long, 4-inch-diameter discharge line would deliver the geyser flows to the evaporation reservoir. A small equalizing reservoir, about 55,000 gallons, adjacent to the geyser, would be required to smooth out the flows issuing from the geyser to a steady 0.3-second-foot flow for pumping.

The reconnaissance estimate of the engineering and construction cost for the Crystal Geyser Salinity Control Project is $280,000. Details of the estimated costs are as follows:

Crystal Geyser Dam and Evaporating Reservoir	$250,000
Equalizing Reservoir, pump, and discharge line	30,000
Total construction and engineering cost	$280,000
Annual OM and R	1,500
Colorado River stream depletion replacement (204 acre-feet at $2 per acre-foot per year)	408

CONTROL OF IRRIGATION RETURN FLOWS

Salt loads contributed by irrigation are carried into the river system by irrigation return flows. Thus, these salt loads may possibly be reduced by intercepting return flows for treatment or disposal, by reducing the volume of return flows, and by reducing the salt pickup per unit volume of return flow. Since irrigation return flows represent a large, potentially controllable source of salt loading, several research and demonstration projects have been initiated in this field. Specific activities in the Upper Basin are detailed below.

Treatment and Disposal of Return Flows

Return flows frequently reach the river system as diffuse discharges spread over large areas. However, in some cases return flows may be concentrated by drains or small tributaries. Such flows can then be intercepted and controlled by evaporation, desalination, or deep-well disposal. Only the more saline return flows should be disposed of by evaporation or deep-well injection. Water lost by such disposal of the more dilute return flows would offset the reduction in salt loading with no decrease in the salinity concentration of downstream flows.

Evaporation. Complete control of collected return flows can be achieved by storage in an evaporation reservoir. Such a reservoir must be located in a closed basin or must be impervious to prevent seepage from returning salt to the river system.

The Bureau of Reclamation has investigated the feasibility of utilizing evaporation reservoirs to control saline return flows from Desert Seep Wash and Washboard Wash in the Emery County Project, Utah, and from Little Salt Wash in Grand Valley near Fruita, Colorado.

Reconnaissance plans were prepared for an evaporation reservoir located on Desert Seep Wash. This reservoir would evaporate about 4,300 acre-feet (the non-irrigation season return flow) and store 40,000 tons of salt per year at an estimated cost of $4,920,000. The less saline irrigation season return flows and part of the summer storm floods would bypass the evaporating reservoir through a 3.6-mile-long, 70-second-foot bypass canal. Only an emergency type spillway and no outlet works would be provided. Flood storage of 9,000 acre-feet would provide for storage of the 24-hour design flood flows in excess of 70 second-feet.

In the Grand Valley, a possible evaporation pond site between Little Salt Wash and Adobe Creek was investigated. As no natural reservoir basin is available, it would be necessary to construct an encircling dike varying in height from zero to over 20 feet. Reconnaissance plans were prepared for a pond of 290 acres which would evaporate about 1,000 acre-feet per year at an estimated cost of $2,600,000. By selection of only the higher saline return flows, this evaporation pond would prevent 5,000 tons of salt per year from entering the Colorado River.

The costs of these two salinity control projects are considered greater than the benefits they would produce. However, these studies do indicate the conditions necessary for an economically feasible evaporation project. A necessary requirement is a shallow offstream basin or reservoir site which would have sufficient area to evaporate a design flood for the drainage area above the reservoir as well as the saline flows unless flood flows can be bypassed around the reservoir. Investigations to date indicate that the evaporation of saline flows in the Upper Colorado River Basin, except in isolated instances, will probably be uneconomical.

Deep-Well Injection. Disposal of saline return flows by injection via wells into deep formations is technically feasible. However, data collected by the Bureau of Reclamation indicate that disposal by deep injection probably would not be an economically feasible control project. Most areas of saline return flows are underlain by sandstones at depths of 1,500 to 10,000 feet. Disposal wells drilled into these formations might be able to inject flows of about one-half second-foot or less or a maximum of about 350 acre-feet per year per well. Cost of drilling the wells depends on the depth and would likely vary from $20,000 to over $100,000 per well. All the water to be injected would have to be clarified to prevent plugging the well. It is estimated that the average injection well would be about 4,000 feet deep and that the construction cost of an average project, including injection wells and clarification structures, would be over $400,000 for an injection rate of 1,000 acre-feet per year. Annual operation costs have not been estimated. The salinity concentrations of the return flows vary from less than 1,000 to over 4,000 parts per million with an average of about 2,000 parts per million. Thus, for average conditions the estimated construction cost for disposal of about 3,000 tons of salt per year would be about $400,000.

The Upper Colorado River Basin contains numerous geologic faults and other phenomena. The possibility of changing the stress concentrations in some areas with a resultant earth movement and possible damage to natural surface formations could be a factor limiting application of this method.

It is possible that the only economically feasible way to use injection wells would be to utilize existing abandoned oil or gas wells. It would be necessary to drill out the cement plug, install casing and screens, and clean the drilling mud from the formation which would receive the injected flows. The feasibility of injecting saline flows into deep formations in this manner will receive further consideration.

Desalination. At the present time, it is not economically feasible to control irrigation return flows by desalination. In addition to the high cost of construction and operation of a desalination plant of this scale, disposal of the concentrated brine would be a serious problem. A geologic-closed basin or salt-water body would be desirable for brine disposal. As neither geologic-closed basins or salt-water lakes are available in the Upper Basin, it would be necessary to construct evaporating reservoirs with sealed basins. As discussed before, suitable evaporating reservoir sites are not available where irrigation return flows enter the Colorado River system.

Minimizing Return Flow Volumes

The interrelationship between return flow and salt pickup is not fully understood. However, it is believed that salt pickup from most areas will decrease if return flow is reduced. Also, reduced return flow volumes increase the feasibility of controlling such salt sources for treatment or disposal. Thus, the reduction of return flows by such methods as irrigation management and canal lining has been investigated as a potential salinity control measure.

Irrigation Management. By improving irrigation efficiency through application of techniques discussed in Chapter V, the volume of water wasted in the irrigation of a given field can be reduced with a comparable reduction in return flows. The salinity control benefits of changes in irrigation practices and irrigation efficiency are not well defined at this time. However, research currently being conducted in the Upper Basin by the Utah State University and the Bureau of Reclamation and research under way in other areas should provide a better estimate of the extent of salinity control that can be achieved in this manner.

Canal Lining. Seepage from canals, laterals, and farm distribution systems is excessive in some areas in the Upper Basin and contributes significantly to return flow volumes. This seepage can be readily controlled by lining the canals and laterals and by installing pipe distribution systems. Reductions in seepage resulting from such construction can be closely predicted. However, the salinity control benefits of reducing seepage are not well defined at this time.

Some canal lining has been completed in the past by local irrigators and by the Bureau of Reclamation. Additional lining will be completed in the near future. Some estimates of lining costs have been prepared. Research and demonstration projects to evaluate the salinity control benefits of canal lining are under way. These activities are discussed below.

The Bureau of Reclamation is lining the canals and laterals of recently constructed projects such as the Eden Project in Wyoming and the Hammond Project in New Mexico. Also, some existing canals and laterals will be lined during construction of recently authorized projects such as the Uintah Unit, Central Utah Project; Dolores; and Animas-La Plata Projects. Canals constructed on earlier Bureau projects can be lined through rehabilitation programs.

The Agricultural Stabilization and Conservation Service and the Soil Conservation Service of the Department of Agriculture also have a cost-sharing program to help irrigators, irrigation companies, and irrigation districts line their canals, laterals, and farm ditches.

All of the canals, laterals, and farm ditches with excessive water loss could be lined or placed in pipe under one of the above programs. It is estimated that seepage losses could be reduced by 75 to 85 per cent by such a lining program. However, the irrigators often do not understand the need for the lining and also do not want to pay a part or all of the lining costs as required by the above programs. Some irrigators have no economic incentive to line their systems because they own rights to sufficient flow to allow large conveyance losses, have no drainage problems, and state water right laws prevent sale of any water they would conserve by lining their conveyance system. Any conveyance system lining program developed for salinity control probably would require an economic incentive for the irrigator.

An example of typical seepage problems is the Bureau of Reclamation's Uncompahgre Project in western Colorado. Five hundred and sixty-five miles of canals and laterals on this project deliver about 488,000 acre-feet of water annually to 73,000 acres of irrigated land. It is estimated that 135,000 acre-feet of this water are lost by seepage from the canals and laterals. Additional water is lost by seepage from farm ditches. Other irrigation companies deliver irrigation water through systems with similar problems to an additional 15,000 acres in the Uncompahgre area. Very little canal lining has been completed in this area.

Similar seepage problems have been encountered in nearby Grand Valley. However, a number of miles of canals, laterals, and farm ditches have been lined in this valley.

Large seepage losses also occur from many miles of canals and laterals owned by private irrigation companies in Uintah, Duchesne, Carbon, and Emery Counties in Utah, from similar facilities in the Green River drainage of Wyoming, and from private works in the San Juan River drainage in southwestern Colorado and northwestern New Mexico. The magnitude of these water losses and the length of canals which could be beneficially lined have not been determined.

By conserving water through reduction of seepage losses, the available water supply within a given subbasin may be increased. However, the net water supply available for salinity control downstream from the subbasin would remain relatively unchanged as such seepage losses generally return to the river system as irrigation return flow. Thus, the same volume of water would leave the subbasin with only the flow path changed.

In a number of cases it is possible, however, that increasing a subbasin's available water supply by reducing seepage losses would actually reduce the downstream flow available for salinity control. Under existing water rights laws, the surplus water would probably be utilized to irrigate additional land within the subbasin with the result that consumptive use would be increased and net subbasin outflow decreased. The Uncompahgre Valley demonstrates the potential for such increased consumptive use. Over 60,000 acres of non-irrigated arable lands are located in this valley. Placing only a fraction of this land under irrigation could utilize a major portion of the potential water supply obtainable by reducing seepage losses. Thus, it is probable that the water conservation aspects of canal lining will not provide additional water for salinity control. However, the salinity control achieved by reducing return flow volumes and salt pickup may be significant.

Lining canals can require a large expenditure of capital by an irrigation project. Costs are dependent upon such factors as canal capacity and location and the type of lining utilized. In addition, the cost per irrigated acre is also dependent upon the relative lengths of canals and laterals required to deliver the water.

The Bureau of Reclamation has estimated average lining costs for several areas. An area of 6,900 acres in Grand Valley near Fruita, Colorado, was surveyed to determine the cost per acre to line canals and laterals for the Grand Valley and Uncompahgre areas. Reconnaissance estimates were prepared for lining the 44 miles of canals and laterals serving the study area and a $300-per-acre cost of lining determined. There are also 57 miles of farm ditches in the study area which would cost an estimated $250 per acre for lining. These costs are probably sufficient for the Uncompahgre area where only minor amounts of the distribution system have been lined. For the Grand Valley area, the costs may be slightly higher as some laterals and farm ditches have been lined (about 15 per cent in the Fruita area).

Estimated costs of providing two-inch thick concrete lining for canals and laterals in the 3,930-acre Hammond Project and a 3,000-acre block of land in the Florida Project were utilized to derive an average cost of $250 per acre for lining canals and laterals in the San Juan River Basin in Colorado, New Mexico, and Utah. Per-acre costs for canal lining programs were not computed for the Price River-Emery County areas and Duchesne River area in Utah. However, the estimated costs of lining selected reaches of canals indicate that the per-acre cost would probably not exceed $300. No lining costs were estimated for the Green River drainages in Wyoming, but they would also probably be $300 or less per acre.

The above cost figures are based on the lining of all canals and laterals. Ponding tests are needed to determine which reaches of existing canals should be lined. If such tests indicate that the full length of the canals and laterals does not need to be lined, the above costs probably could be reduced but not necessarily proportionately as lining several short reaches of a canal costs more than lining the same length canal in one reach. The cost of lining small laterals and farm ditches could be reduced if the irrigators organized and did the work themselves. As more lining is completed in the basin, cost estimates can be refined.

A canal lining demonstration project supported by FWPCA funds was initiated in July 1968 in Grand Valley, Colorado. This project will demonstrate the salinity control effects of reducing seepage by canal lining. Pre-construction data collection was completed during the summer of 1969 and several miles of canal lining were completed in the three study areas during the late fall. Refinement of cost estimates for the Grand Valley should be possible following completion of lining activities. Evaluation of the salinity control effects will continue through 1971. Canal lining was done by local irrigation districts and the Colorado State University is conducting the data collection and evaluation activities.

Minimizing Salt Pickup

The mechanisms controlling the pickup of salt by irrigation return flow as it passes through the soil and groundwater aquifer and back to the river system are not fully understood. As discussed above, it is believed that reducing return flow volume may reduce salt pickup. Thus, some effort has been expended in investigating the feasibility of flow control. It is also known that certain soil types and rock formations contribute large salt loads. Reducing the opportunity for return flow to contact these salt sources shows promise of yielding some salinity control benefits. However, the majority of current activity in this field is directed toward obtaining a better understanding of salt pickup mechanisms.

A major research effort to develop and field-test techniques for predicting the salinity of irrigation return flows, to develop a better understanding of salt pickup mechanisms in the soil and groundwater aquifer, and to evaluate the salinity control effects of various irrigation management techniques has been initiated in Ashley Valley, Utah. This valley has been irrigated for almost a century by private irrigation districts. Since 1956, supplemental water supply has been provided much of the valley by the Vernal Unit of the Bureau of Reclamation's Central Utah Project. A joint research project, funded by the FWPCA and staffed and operated by the Bureau of Reclamation, was initiated in the valley in May 1969. Research is scheduled to continue for 4-5 years. Intensive data collection will allow evaluation and refinement of several models developed by the Bureau to predict the salinity of return flow. This research should provide increased knowledge of salt pickup mechanisms. Development of the models will provide the tools for predicting and evaluating the salinity control effects of various measures such as canal lining, improved irrigation efficiency, etc. Should the results of the first year or two of this research indicate the need, similar research will be initiated in a second study area with different soil and topographical characteristics to provide additional range to the prediction models.

Other related research has been proposed to increase salinity control knowledge. One proposal currently under review would establish a research farm in the Vernal study area to evaluate the salinity control effects of irrigation management practices and provide field-scale verification of current laboratory research concerning salinity relationships in the soil root zone. This research could be closely coordinated with the Bureau's research activities.

Another research proposal under consideration deals with salinity relationships in groundwater as related to irrigation return flow. It is probable that additional research in the irrigation field will be initiated in the near future to aid in the development of salinity control measures.

With the exception of the Grand Valley Project, no salinity control projects directly related to irrigation have been initiated. It is hoped that the above research will develop feasible control methods within the near future. Demonstration projects will be initiated where indicated to develop estimated control costs.

CHAPTER VII. LEGAL, INSTITUTIONAL, AND FINANCIAL CONSIDERATIONS

The range of choice of salinity control projects is not infinite. The selection of projects is limited by physical conditions and costs of alternatives. Selection is also limited by the institutions, laws, policies, and administrative arrangements that govern water management and use. Although institutions are man-made and therefore mutable, often they have been hardened by usage or are accepted as inflexible and thus they limit the range of choice. Finally, views of the desirable and practical are colored by cultural factors.

The Colorado River Compact, the Upper Colorado River Basin Compact, the Mexican Treaty, and the Arizona vs. California suit in the Supreme Court divides the Colorado River water among each of the states and Mexico without respect to water quality. The Congressional Acts for projects in the Colorado River Basin and the repayment contracts between the Bureau of Reclamation and the water users provide for the delivery of a definite amount of water by the United States to the water users also without reference to the salinity concentration of the water.

Until recently, state water laws have also given little attention to the quality of water when division has been made among legally recognized users. However, as water quality data become more prevalent and effects of quality changes become widely understood, it appears that future adjudications will give greater weight to water quality aspects when settling water rights disputes.

Water laws in each of the states provide for a priority of use of water. Domestic or municipal use ranks first followed generally by industrial and agricultural use. Other uses rank lower. Only nominal recognition has been given to water quality control as a beneficial use. State water laws, especially those governing appropriation of direct flow rights for irrigation, tend to encourage excessive use.

Since the Colorado River is completely controlled and insufficient water is available for all desirable uses, each of the Colorado River states jealously guard their share of the water. The Colorado River Compact appears to restrict the transfer of water rights from one basin to the other. As the salinity control projects discussed in this report, while located in the Upper Basin, primarily benefit the Lower Basin water users with only incidental benefits in the Upper Basin, the states of the Upper Basin are reluctant to approve a consumptive use for salinity control project for which they will receive no direct benefit.

The above listed compacts, treaty, court suit, contracts, and state water laws all tend to make salinity control in the Colorado River difficult. Most salinity control projects will also consumptively use water and since state water laws do not consider this use a beneficial one, the projects will be stymied unless another source of water is found to replace the water consumptively used.

LEGAL AND INSTITUTIONAL ASPECTS

Federal Legislation

The Federal Water Pollution Control Act (P.L. 84-660), amended by the Federal Water Pollution Control Act Amendments of 1961 (P.L. 87-88), the Water Quality Act of 1965 (P.L. 89-234), and the Clean Water Restoration Act of 1966 (P.L. 89-753).

The Secretary of the Interior is directed by the above law to undertake studies and conduct research necessary to prevent pollution and restore the quality of the interstate streams and waters of the United States. Section 10-C-3 also directs the states to establish water quality standards for all interstate streams. These standards must be designed to enhance water quality and must consider all legitimate uses. Senate Report No. 10 on the 1965 amendments states: "The Committee must reemphasize its interest that water quality standards are not designed to 'lock in' present uses of water or to exclude other uses, not now possible. The standards are not a device to insure the lowest common denominator of water quality but to enhance the quality and productivity of our water resources."

Senate Report No. 10 also states: "The Committee intends that water quality standards should be applied on the basis of water quality requirements of present and future uses of a stream or section of a stream, after due consideration of all factors and variables involved."

Executive Order 11288, July 2, 1966, issued to implement the above Water Pollution Control Act, directs the Secretary of the Interior to review all plans and supporting data of all Federal water resource development projects relating to water quality and prepare a report to the head of the responsible establishment describing the potential impact of the project on water quality, including recommendations concerning any changes. The report of the Secretary of the Interior is to accompany any report proposing authorization or construction of such water resource development project.

Guidelines for Establishing Water Quality Standards for Interstate Waters, May 1966, prepared by the Department of the Interior, suggests that the states should design water quality standards to "enhance the quality of water," and that the standards "should include consideration of all relevant pollution sources, such as . . ., irrigation return flows . . ."

Numerical standards for salinity concentration were not set for the Colorado River streams because it was recognized that these water quality standards could drastically restrict present and future uses of the Colorado River water under the existing compacts. The seven Colorado River Basin states therefore agreed among themselves and recommended to the Secretary of the Interior that specific numerical limits on salinity should not be established in the state standards with regard to the Colorado River and its tributaries until further detailed studies were made which would give a better basis for selection of the limits.

Steward Udall, then Secretary of the Interior, expressed his views concerning the quality of water standards for the Colorado River in his statement of January 30, 1968, to the House Subcommittee on Irrigation and Reclamation. Part of his statement said: ". . . I would like to state that salinity standards will not be established until we have sufficient information to assure that such standards will be equitable, workable, and enforceable. . . . Salinity standards must be so framed that they will not impede the growing economy of the Colorado River Basin and yet not permit unwarranted degradation of water quality."

The Colorado River is completely controlled and used with no waste to the sea. This means that the limited water supply in the Colorado River must be used and reused for a wide variety of purposes. Also, each of the states has been apportioned a part of the flow of the Colorado River by the two Compacts and the Supreme Court. Each of the states is entitled to a given amount of the Colorado River flow. Water quality standards, if too restrictive, could restrict the states in developing full use of their water rights.

Colorado River Compact

Water of the Colorado River was divided between the Upper and Lower Colorado River Basins by the Colorado River Compact which was signed in 1922 by a commissioner of each of the seven states of the river basin and by a representative of the United States. All states but Arizona ratified the Compact prior to its effective date in 1929. The dividing point on the river between the Upper and Lower Basins is at Lees Ferry which is defined as a point one mile below the mouth of the Paria River. The Compact apportions to each of the Upper and Lower Basins in perpetuity for exclusive beneficial consumptive use a total of 7,500,000 acre-feet annually. In addition to the apportionment of 7,500,000 acre-feet, the Lower Basin is given the right to increase its beneficial consumptive use of water from the Colorado River system by 1,000,000 acre-feet annually. The Compact further provides that the states of the upper division will not cause the flow of the river at Lees Ferry to be depleted below an aggregate of 75,000,000 acre-feet for any period of 10 consecutive years.

One of the provisions in the Compact permits exportation of the water out of the Basin as long as it is used beneficially in the seven basin states and another provision recognizes the obligation of the United States to the Indian tribes. The Compact prescribes the manner in which the waters of the Colorado River system may be made available to Mexico under any water rights recognized by the United States. The Compact made no provision concerning salinity concentration or load.

Mexican Treaty

The treaty with Mexico, signed in 1944, provides basically for a guaranteed annual delivery by the United States to Mexico of 1,500,000 acre-feet of Colorado River water. This treaty also required the United States to construct Davis Dam to make possible the regulation at the boundary of the waters to be delivered to Mexico.

Upper Colorado River Basin Compact

The Upper Colorado River Basin Compact, signed in 1948, apportions the Upper Basin's share of the Colorado River water 50,000 acre-feet annually to Arizona and the remaining water as follows: Colorado - 51.75 per cent; New Mexico - 11.25 per cent; Utah - 23.00 per cent; and Wyoming - 14.00 per cent.

Arizona vs. California Suit in the Supreme Court

The states of the Lower Basin have agreed to a compact for the division of the waters of the Lower Colorado River Basin. The State of Arizona filed suit in the Supreme Court of the United States in October 1952 against the State of California and others for the determination of the rights to use the waters of the Lower Colorado

River system. The Supreme Court gave its decision on June 9, 1963, and issued a decree on March 9, 1964, providing for the apportionment of the use of the waters of the main stream of the Colorado below Lees Ferry. The main impact of the decree will be to decrease the amount of Colorado River water presently used by California water users and to increase that used by Arizona water users.

Projects Acts of the United States Congress

The Colorado River Compact cleared the way for the Congress to pass the Boulder Canyon Project Act in 1928, authorizing construction of Hoover Dam and the All-American Canal System. The All-American Canal System delivers water to the Yuma, Imperial, and Coachella Valleys in California, and to the Gila and Yuma Projects in Arizona. Other major irrigation developments which benefit from Hoover Dam's control and regulation of the river include the Palo Verde Valley and the Colorado River Indian Reservation.

When Hoover Dam provided control of the river, Parker Dam was constructed in 1934-1937, with money advanced the Metropolitan Water District of Southern California, to form a forebay from which the Metropolitan Aqueduct could draw off the needed water.

Passage in 1956 of the Colorado River Storage Project by Congress authorized the construction of Flaming Gorge Dam, the Curecanti Dams, Navajo Dam and Glen Canyon Dam, and eleven participating projects in the Upper Basin. All of the dams except Crystal Dam of the Curecanti Unit have been constructed. Nine of the authorized participating projects and three of another five participating projects authorized at a later date are under construction or have been completed. Water quality studies have been required by the legislation authorizing construction of some of the above projects in the Upper Basin.

Passage in 1968 of the Colorado River Basin Project Act (Central Arizona Project) authorizes five more participating projects in the Upper Basin, provisionally authorizes another participating project, and set a date for completion of an authorizing report for still another participating project.

Repayment Contracts Between Water Users and the Bureau of Reclamation

The Bureau of Reclamation has repayment contracts with the water users for the completed projects listed above, which generally require delivery of a quantity of water to each farm sufficient to irrigate the cultivated land with irrigation efficiencies of 50 per cent or less. These repayment contracts cannot be altered to require higher irrigation efficiencies without consent of the water users. None of the repayment contracts mention water quality in regards to the salinity concentration of the delivered water or the return flow.

State Water Laws and State Water Control Agencies

The state water laws appropriate irrigation water as direct flow rights and as storage rights. Water users with direct flow rights use a continuously flowing stream. If an irrigator with direct flow rights does not use all his water right, he may lose part of it. The provision in the appropriation law that an irrigator may lose his water right if he does not use it encourages excessive application of irrigation water and poor irrigation practices which result in lower on-farm irrigation efficiencies. Storage rights, however, generally encourage more conservative application of irrigation water and irrigation practices which result in higher on-farm efficiencies because the water not used can be held over for use the next year if necessary.

Some state appropriation laws tie the direct flow right to a particular piece of land and the irrigator is not allowed to use it on other land. Thus, shallow soils over highly saline shales may be irrigated in place of better soils in another area.

None of the state water laws consider consumptive use of water for quality control a beneficial use. State water laws generally are administered by the state engineer. Other state agencies, however, also exercise some control functions. The State Division of Health or the State Water Pollution Control Division, or both, usually administer the state water quality standards. Water Resources Divisions are also planning for the best and complete use of all water resources within the state. Each of these agencies usually has authority and issues rulings and directives affecting use of water within the state.

The Upper Colorado River Commission

The Upper Colorado River Commission was created by the Upper Division states to serve as an interstate administrative agency to secure the expeditious agricultural and industrial development of the Upper Basin. The Commission makes engineering studies and performs other functions in furthering this development.

Conservation, Irrigation, and Drainage Districts, and Companies and Other Water User Organizations

These water user organizations are usually local organizations to administer the delivery of irrigation water and provide drainage for the farmers. A few may encompass several counties and serve municipal and industrial users as well as farmers. All of them guard their water rights and attempt to operate at the lowest cost to the water user. Most of these organizations operate on minimum budgets; therefore, in general, they are reluctant to finance lining and drainage projects or programs to improve irrigation efficiencies unless there is a financial incentive.

Other Federal and State Agencies Administering Watershed Lands

The U. S. Forest Service administers most of the high areas where the heavier precipitation occurs and where most of the water flowing in the Colorado River system originates. The Forest Service controls the grazing, lumbering, recreation, and other developments on forest lands. It also has programs to improve the grazing range, reseed or replant forest trees, control erosion, and reduce the speed of the runoff from snow melt and rainstorms. All of the above programs will affect both the intensity and volume of the stream flow from the forest lands.

The U. S. Bureau of Land Management administers most of the remaining federal Colorado River watershed lands. The Bureau of Land Management has programs to improve the range by clearing brush, shrubs, and trees of slight value and replanting with improved varieties of grass. It also constructs stock watering ponds, sediment retention ponds, erosion control structures, and spreading ditches to divert the runoff from heavy storms to areas where it will percolate into the ground without creating an erosion problem.

The effect that the Forest Service and Bureau of Land Management programs have on the salinity load in the Colorado River is not known.

State Land Agencies, State Fish and Game Agencies, and State Park Agencies also administer some watershed lands. The area administered by them is small compared to the area administered by the Forest Service and the Bureau of Land Management; however, the effects of their programs on the salinity load of the Colorado River would probably be similar.

FINANCIAL ASPECTS

Nearly all of the benefits of salinity control projects would accrue to users in the Lower Colorado River Basin. Benefits are scattered among irrigation, industrial, and municipal users. Benefits to the irrigators vary depending on the crop they are growing, the amount of water available to them for irrigation, the cost of the water delivered to the farm, and the labor cost for irrigating. If the farmer is growing salt-tolerant crops, he would not receive any direct benefit. Benefits to industrial users vary according to what the water is used for and salinity concentration requirements of any process water used. Some industries may receive very little if any direct benefit from a salinity control project. Municipal users would benefit by receiving water with reduced hardness which would reduce the water softening costs or the soap and detergent costs. An equitable assessment of project costs in proportion to benefits would be extremely difficult and would require adjustments each year.

The water users in the Upper Basin contribute to the salt load of the Colorado River and also increase the salinity construction of the river by consumptive use of pure or low salinity water which would otherwise dilute the river water, thereby reducing the salinity concentration. An equitable assessment of project costs against water users in the Upper Basin is impossible or improbable at this time because salinity quality records were not obtained prior to most of the irrigation developments, and it is therefore impossible to determine the salinity concentration contributed by these irrigated areas.

Because of the widespread benefits obtainable by salinity control projects and the difficulty in determining the salinity concentration contributed by specific water users, the costs for constructing salinity control projects probably should be non-reimbursable.